2015-1778

In The
United States Court of Appeals
For The Federal Circuit

ELECTRIC POWER GROUP, LLC,

Plaintiff – Appellant,

v.

ALSTOM S.A., ALSTOM GRID, INC., PSYMETRIX, LTD., ALSTOM LIMITED,

Defendants – Appellees.

APPEAL FROM THE UNITED STATES DISTRICT COURT FOR THE CENTRAL DISTRICT OF CALIFORNIA IN CASE NO. 2:12-cv-06365-JGB-RZ, JUDGE JESUS G. BERNAL.

BRIEF OF APPELLANT

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CERTIFICATE OF INTEREST

Counsel for Plaintiff-Appellant Electric Power Group, LLC certifies the following:

1. The full name of every party or amicus represented by me is:

   Electric Power Group, LLC.

2. The name of the real party in interest represented by me is:

   Electric Power Group, LLC.

3. All parent corporations and any publicly held companies that own 10 percent of the stock of the party or amicus curiae represented by me are listed below.

   Not applicable.

4. The names of all law firms and the partners or associates that appeared for the party or amicus now represented by me in the trial court or agency or are expected to appear in this court are:

   Christie Parker & Hale, LLP: David A. Dillard, Art Hasan, G. Warren Bleeker, Katherine L. Quigley, Michael A. Koplow and Kyle W. Kellar

Dated: October 14, 2015

Respectfully submitted,

/s/ Art Hasan

Art Hasan

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Parties

EPG	Plaintiff-Appellant Electric Power Group LLC
Defendants	Collectively, Defendants Alstom, S.A., Alstom Grid, Inc., Psymetrix Ltd., and Alstom Limited.

Patents-in-Suit

the ’843 Patent	U.S. Patent No. 7,233,843 (system claims 4, 7, 9, 12, 19, and 24 at issue)
the ’259 Patent	U.S. Patent No. 8,060,259 (system claims 1, 5, 38, 49, and 53, and method claims 18 and 21 at issue)
the ’710 Patent	U.S. Patent No. 8,401,710 (system claim 9 and method claims 12 and 17 at issue)
asserted claims	Collectively, claims 4, 7, 9, 12, 19 and 24 of the ’843 Patent, claims 1, 5, 18, 21, 38, 49 and 53 of the ’259 Patent, and claims 9, 12 and 17 of the ’710 Patent.

Defined Terms

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STATEMENT OF RELATED CASES

Pursuant to Federal Circuit Rule 47.5, EPG provides as follows:

(a) There have been no previous appeals in this case; and

(b) EPG is not aware of any other cases that will directly affect or be directly affected by the Court's decision in this case.

JURISDICTIONAL STATEMENT

This appeal arises from a decision of the U.S. District Court for the Central District of California, Judge Jesus G. Bernal. The district court had jurisdiction under 28 U.S.C. §§ 1331 and 1338(a). The district court entered final judgment on May 21, 2015. EPG timely filed a Notice of Appeal on June 19, 2015. This Court has jurisdiction under 28 U.S.C. § 1295.

STATEMENT OF THE ISSUES

On *de novo* review, the issue is whether the district court erred in granting summary judgment of patent subject matter ineligibility under 35 U.S.C. § 101, where the claims provide a monitor for the electric power grid that receives and transforms real-time raw data to specifically enumerated power grid metrics to visualize the real-time dynamic status of the power grid over a wide area and to provide an operator with situational awareness of the health and stability of the grid, which implicates the following sub-issues:

1. Whether the district court erred in finding the asserted claims are directed to an abstract idea, in which the alleged idea does not account for critical limitations of the claim and is inconsistent with multiple different characterizations provided by the Defendants.

2. Whether the district court improperly disregarded a line of legal authority holding that claims directed to the monitoring, transformation and presentation of specifically enumerated data that characterize the intrinsic functioning of a machine or body are not abstract.

3. Whether the district court erred in finding that the asserted claims fail to supply any "inventive concept," in which the district court overly distilled the claims into alleged "conceptual elements" that omit significant amounts of material claim language.

4. Whether the district court erred by ignoring substantial, unrebutted testimony from EPG's expert identifying and explaining, from the standpoint of one skilled in the art, the meaning of material claim limitations that significantly narrow the scope of the asserted claims and remove them from being directed solely to an alleged abstract idea.

STATEMENT OF THE CASE

I. PROCEDURAL BACKGROUND

Plaintiff Electric Power Group, LLC ("EPG") is a developer and distributor of systems for monitoring of the electric power grid. A2479 at ¶ 9; A4992-5003. On July 25, 2012, EPG sued its head-to-head competitors, Defendants Alstom, S.A., Alstom Grid, Inc. and Psymetrix Ltd., for infringement of U.S. Patent No. 8,060,259 (the "'259 Patent"). A2448. Later, in February 2013, EPG filed its First Amended Complaint, additionally alleging infringement of U.S. Patent No. 7,233,843 (the "'843 Patent"). A2450. In June 2013, EPG filed its Second Amended Complaint, additionally alleging infringement of U.S. Patent No. 8,401,710 (the "'710 Patent"). A2452. In April 2014, EPG filed its Third Amended Complaint, adding Alstom Limited as a Defendant. A2477-84. The Patents-in-Suit are continuations of one another, share a common specification, and claim priority from a common provisional application filed August 8, 2003. A40; A99; A159.

During the pendency of the action, EPG narrowed the claims it was asserting to the following: claims 1, 5, 18, 21, 38, 49 and 53 of the '259 Patent; claims 9, 12 and 17 of the '710 Patent; and claims 4, 7, 9, 12, 19 and 24 of the '843 Patent. A23-24.

On November 3, 2014, Defendants filed, *inter alia*, a Motion for Summary Judgment of Invalidity and Non-Infringement under 35 U.S.C. § 101 as to all of the asserted claims (A2732-50), and EPG filed, *inter alia*, a Motion for Partial Summary Judgment of Infringement (A3324-52) and a Motion to Exclude Testimony and Opinions of Defendants' Noninfringement and Invalidity Expert Virginia Lee (A2844-68). On May 21, 2015, the district court granted Defendants' motion for summary judgment and denied as moot all of the other then-pending substantive motions. A23-31.

II. BACKGROUND TO THE ART

A. <u>Electric Power Grid Background</u>

The electric power grid is a complex, interconnected and dynamic machine. That complex machine is formed of hundreds of thousands of power sources, generators and switches. Millions of miles of high voltage transmission lines interconnect these components. A4869 ¶20; A4900 ¶1; A5011-14; A7275. The U.S. electric power grid alone is the largest machine *in the world*. The U.S. electric power grid includes approximately 3,200 separate utilities generating and transmitting $400 billion worth of electricity. This massive amount of energy is transmitted over 2.7 million miles of high voltage power lines spread out across three synchronized areas or interconnections. *Id*. Despite the physical enormity of this electrical distribution machine, each of the thousands of power plants and

millions of miles of transmission lines must operate in synchronicity within each interconnection to provide stable three phase power output at 60 cycles per second (60 Hz) to all end users, including residential homes and businesses. A4869 ¶20; A5016.

Because electricity for a power grid cannot be easily stored, electricity must be generated and supplied the instant demand arises. Such demand changes from instant to instant. A5016; A7275. Notwithstanding these instantaneous demands, there ultimately remains the need for stable operation, whereby the amount of generated electricity must be balanced between the load on the grid and the capacity of its transmission network. *Id.* Too little power supplied for a given demand (insufficient generation) or too much power supplied (overload of a portion of a power grid) can both readily lead to instability and power system faults that, without intervention, can lead to physical damage of power grid infrastructure, interruption of power supply to customers and blackouts. *Id.*; A4869-70 ¶¶23-25; A5016; A7311. Further complicating the intricate nature of the U.S. power grid is the constant threat of physical damage to a power grid component. A single power line downed during a storm or a mechanical failure in but a single generator can both cause a fault, unexpectedly increase load burden on other power grid components that must compensate for the downed component,

and—if not properly monitored and controlled—result in damage to or collapse of one or more portions of the grid. *See* A4873.

Cascading failures, where one component after another overloads and faults, can occur when other power grid components cannot compensate when a fault occurs. A4961; 5016; A6669. Cascading failures can result in an uncontrollable ripple effect over a wide area of the grid. This can occur if nearby generators (such as generators in neighboring jurisdictions) cannot supply the power generation needed due to a downed generator, or if nearby power lines cannot handle the increased load due to a downed power line. A4961; 5016; A6669. These "cascading faults" or "cascading failures" spread rapidly across the grid and cause massive blackouts if prompt and accurate intervention is not taken. An example of such a cascading failure is the August 2003 blackout, that affected an estimated 50 million people in the United States and Canada. A7311.

Numerous different entities, such as utilities and reliability coordinators, are responsible for the generation, transmission and distribution of electricity. *See* A142 at 1:36–52.[1] Each entity is responsible for its own jurisdiction, also generally known as a control area. *Id.* Prior to the development of the inventions embodied in the Patents-in-Suit, each utility operated a local area monitoring

[1] The Patents-in-Suit are continuations from one another and share a common specification. Unless otherwise indicated, all specification cites are to the '259 Patent. A99-158.

system that gave estimated information concerning power sources, transmission lines and switches in its control area and its control area alone. *Id*. at 2:2–13. As a result of these inefficient silos of information, an operator in one control area was unable to engage in real-time monitoring of disturbances occurring in neighboring control areas. *Id.*; A4867–69 ¶¶13-18. Because then-existing systems did not allow operators to assess real-time disturbances in neighboring control areas, this negatively impacted grid stability in the control area of other operators in that they would ultimately lack sufficient time to take preemptive action to maintain stability of the grid when a neighboring power component would fail. *Id.* As explained in the Background section of the Patents-in-Suit:

> Due to the enormous task at hand, there are a number of organizations responsible for overseeing these power generation, transmission and distribution activities. For example, there are over 3,000 utilities, thousands of generators, 22 Reliability Coordinators, and 153 Control Areas (CAs) in the United States for monitoring and control of generation, transmission and distribution of electricity. While all these different entities at various different levels are involved in generation, transmission and distribution of electricity as well as monitoring and control in a power grid, there is no single integrated system that can be used to monitor and manage the electric power grid in real-time across all of the different elements of the power system.

A142 at 1:63–2:8.

B. <u>Prior Methods of Electric Power Grid Monitoring</u>

Local-area monitoring systems as they existed in 2003 were incapable of being "scaled up" to achieve real-time, wide-area monitoring. A142 at 2:2-14;

A4875–76 ¶¶45-47. Those systems, commonly known as SCADA ("Supervisory Control and Data Acquisition") systems (A4966), monitored line voltages, frequency, power flows and generator output readings in a local area, such as within an individual utility or control area. A4875–76 ¶¶45-47; 4874 ¶41. The systems could not perform real-time, wide-area monitoring because SCADA measurements are acquired at relatively slow rates and are not time synchronized. *Id*. The then-existing systems were equally incapable of presenting massive amounts of fast moving data in a coherent manner. *Id*.

As distances between the control center and the portions of the grid being monitored expand over a wide-area, the lack of time-stamping in SCADA measurements multiplies and prevents acquired signals from being accurately synchronized and compared to one another. A4875–76 ¶¶45-47; 4874 ¶41. As a result, the unsychronized SCADA measurements were useless by themselves to monitor real-time dynamic divergences (e.g., growing differences between measurements across the grid) occurring between geographically dispersed areas of the grid in real-time. A4874 ¶39; A4875-76 ¶¶45-46. The inability to utilize this information is critical in that any of the aforementioned divergences on the grid can trigger cascading failures and blackouts. A4870 ¶24.

Further complicating any comprehensible real-time monitoring of a wide-area network is that SCADA data is only received at the relatively slow rate of one

measurement every few seconds. A4874 ¶39. Stable power output to an end user requires sub-second operation at 60 cycles per second (*i.e.*, 60 Hz). A4869 ¶20; A5016. SCADA data, therefore, is insufficient—without something more—to apprise an operator of the dynamic or transient state of the power grid where disturbances occur at sub-second levels.

Due to the time between received measurements and the ever-changing nature of the power grid, prior art SCADA systems traditionally relied upon "state estimation" models. A4874–75 ¶¶38-43; A4967. These models—at best—estimated and predicted the actual, dynamic state of the electric power grid based on the data available at that time. *Id.* Because the SCADA-based measurements are only intermittently received, the actual "real-time" state of the power grid could not be provided in 2003 by this measurement information alone. And because of the various differences and limitations of the monitoring systems available in 2003, the types of local area systems described in the Background section of the Patents-in-Suit could not be simply "scaled up" or "grown into" a wide-area, real-time monitoring system. A4875–76 ¶¶46-47.

The systems of the time—including the local-area measurement based systems described in the Background of the Patents-in-Suit from 2003—also failed to provide a user interface conducive to presenting the large amounts of data that are necessarily acquired by a wide area system. *See* A4876 ¶47; A4874 ¶40.

Providing wide area power grid status information can quickly overwhelm operators with the incredible amount of rapidly-changing information that is received and must be analyzed. *See* A4879-80 ¶62; A5066 at 1:57–62.

Confined to local areas with a relatively small and manageable amount of data, these local-area systems typically employed "one-line diagram" displays to present information about the state of an individual control area to the operator. A4868 ¶14; A4879 ¶60; A4896; A4898. The earliest monitoring systems for the electric power grid consisted mainly of large display panels with various lights to indicate circuit breaker positions (*e.g.*, open means no power is allowed to flow; closed means power is flowing). Such one-line diagrams were typically accompanied by dials and gauges to indicate various measurements on the grid. A4867–68 ¶13; A4896; A4898. Operators monitored information presented by the gauges and dials for their specific system, with limited to no access to information regarding neighboring power systems to obtain full situational awareness of the interconnection. *Id.* Once built, these large display panels could only be changed or updated to reflect new power grid elements (such as new lines or generators) at a high cost. *Id*.

These early systems only provided operators with direct measurements obtained from the power grid. A4867–68 ¶13; A4896; A4898. The systems gathered and presented relatively slow moving multi-second snapshots of direct

readings, and did not conduct any derivations or calculations on the measured data that could help interpret it. *Id*.

Even with the advent of digital computers, these monitoring systems continued to provide operators information similar to that provided by the light boards and mechanical gauges and dials. A4868 ¶16. The systems continued to utilize one-line diagrams with little more than the added benefit of being more easily updated to reflect changes to the underlying grid, such as the addition of generators or transmission lines. *Id*. These systems still failed to conduct any derivations on measurements and remained unsatisfactory to present the massive amounts of data that would be obtained from measurements obtained over a wide area. *Id*. The systems were also not set up to deal with more than slowly gathered, snapshot measurements. The figure below depicts an example of a one-line diagram.

A5022.

III. THE PATENTED TECHNOLOGY

A. The Patents-in-Suit

The ’843 Patent is titled “Real-Time Performance Monitoring and Management System.” A40–98. The ’259 Patent is a continuation of the ’843 Patent, and is titled “Wide-Area, Real-Time Monitoring and Visualization System.” A99–158. The ’710 Patent, in turn, is a continuation of the ’259 Patent and bears the same title. A159–217. The Patents-in-Suit each claim the priority benefit of a common U.S. provisional application No. 60/493,526, filed August 8, 2003. A40; A99; A159.

Six days *after* the priority date of the Patents-in-Suit—on August 14, 2003, a massive, catastrophic blackout occurred. An undetected electrical component failure in a utility in Ohio rapidly cascaded across the electric interconnection to different distribution centers, causing power failure to vast portions of the Northeastern and Midwestern United States and in Canada, affecting approximately 55 million people and incurring $4 to $10 billion in damages. A4869–70 ¶23; A4958. In response to this blackout, a joint U.S.-Canada task force was assembled to investigate the cause of the blackout and to recommend actions to prevent or minimize future blackouts. A4958. The task force’s April 2004 final report—published approximately eight months after the priority date of the Patents-in-Suit—stated that “[a] principal cause of the August 14 blackout was

a lack of situational awareness" (A4959)—the same situational awareness made possible by the inventions embodied in the Patents-in-Suit.[2,3]

The Patents-in-Suit teach real-time, wide-area monitoring for the electric power grid based on extremely rapid subsecond raw data collected from geographically distributed portions of the grid. Among other things, the patented system:

(1) receives multiple humanly incomprehensible, time stamped, sub-second synchronized phasor data streams from wide-area geographically distinct points over the grid;

(2) transforms the synchrophasor phasor data streams into a narrow subset of particularly enumerated derived metrics selected to provide the operator with a characterization of the dynamic "transient" stability of the grid;

(3) receives specific other types of data, including grid and non-grid data (i.e., SCADA data, transmission line data, geographic map overlays, and weather data);

(4) accumulates and updates the raw data and streaming metric data; and

(5) further transforms and presents the derived metrics in a "concurrent visualization" display interface includes a real-time

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[2] EPG's technical expert, Terry Winter, was part of the panel of experts who authored the report. A4876 ¶47.

[3] In 2007, years after the filing date of the Patents-in-Suit, Defendants filed their own patent application directed to the displays of the accused products. A5046-71. In their application, Defendants proclaimed that visualization systems having geographic overlays and violation makers were necessary to avert blackouts by confronting the "enemies of situational awareness," including "attention tunneling," "data overload" and "complexity creep." A5066; A5069.

> monitoring panel that overlays the streaming metrics with the geographical and other specific grid and non-grid data and juxtaposes additional historical, tracking, and raw data panels to give the operator situational awareness as to the dynamic stability of the grid.

A146 at 9:53–54; A155 at 28:13–56; A216 at 30:66–A217 at 31:51: A4871; A4873–74; A4876; and A5028–29.

Taken as a whole, the inventions embodied and claimed by the Patents-in-Suit enable operators to comprehend massive amounts of humanly incomprehensible data over a wide area while eliminating or reducing the effects of what is sometimes referred to as data overwhelm. A146 at 9:53–66 and A4873–74 ¶37. The asserted claims are directed to the "dynamic stability" of the grid, a term of art that refers to the ability of the grid to remain interconnected (i.e., return to a stable state after an event or disturbance) and operate in synchronism following a real-time, subsecond disturbance. A4883–84 ¶71. The inventions claimed by the Patents-in-Suit provide operators with situational awareness of transient instabilities over a wide area in a real-time manner that allows the operator to rapidly take evasive action to prevent or diminish the effects of cascading faults or other disturbances from remote jurisdictions before they propagate. S*ee generally* A144 at 2:32–46 and 6:20–30.

B. <u>The Asserted Claims</u>

Asserted system claim 1 of the '259 Patent embodies many of the patented features, although additional important features are recited in the remaining claims and the dependent claims. It recites:

> 1. A wide-area real-time performance monitoring system for monitoring and assessing dynamic stability of an electric power grid, the system comprising:
>
> a monitor computer including an interface for receiving a plurality of data streams, each data stream comprising sub-second, time stamped synchronized phasor measurements wherein the measurements in each stream are collected at geographically distinct points over a wide area of the grid;
>
> wherein the monitor computer monitors metrics including at least one of reliability metrics, power grid operations metrics, generation metrics, transmission metrics, suppliers metrics, grid infrastructure security metrics or market metrics over a wide area of the electric power grid, wherein the wide area comprises at least two distinct entities selected from the group consisting of transmission companies, utilities, and regional reliability coordinators;
>
> wherein the monitor computer derives in real-time from the plurality of data streams from the at least two distinct entities selected from the group consisting of transmission companies, utilities, and regional reliability coordinators, one or more dynamic stability metrics including phase angles, damping, oscillation modes, and sensitivities for dynamics monitoring using phasor measurements in which the stability metrics are indicative of grid stress and/or instability, over the wide area; and
>
> wherein the monitor computer is configured to supply at least two different categories of data concern the metrics to a graphical user interface coupled to the monitor computer for concurrently displaying the at least two different categories of data concerning the metrics,

> wherein the categories of data include monitoring data, tracking data, historical data, prediction data, and summary data,
>
> wherein the graphical user interface provides concurrent visualization of a plurality of metrics directed to a wide geographic area of the grid covering at least two distinct entities selected from the group consisting of transmission companies, utilities, and regional reliability coordinators, and
>
> wherein the computer accumulates and updates wide area dynamic performance metrics in real time as to wide area and local area portions of the grid.

A155 at 28:12–56.

The district court, in its summary judgment decision, focused on claim 12 of the ’710 Patent. Claim 12 recites:

> 12. A method of detecting events on an interconnected electric power grid in real time over a wide area and automatically analyzing the events on the interconnected electric power grid, the method comprising:
>
> receiving a plurality of data streams, each of the data streams comprising sub-second, time stamped synchronized phasor measurements wherein the measurements in each stream are collected in real time at geographically distinct points over the wide area of the interconnected electric power grid, the wide area comprising at least two elements from among control areas, transmission companies, utilities, regional reliability coordinators, and reliability jurisdictions;
>
> receiving data from other power system data sources, the other power system data sources comprising at least one of transmission maps, power plant locations, EMS/SCADA systems;
>
> receiving data from a plurality of non-grid data sources;
>
> detecting and analyzing events in real-time from the plurality of data streams from the wide area based on at least one of limits,

> sensitivities and rates of change for one or more measurements from the data streams and dynamic stability metrics derived from analysis of the measurements from the data streams including at least one of frequency instability, voltages, power flows, phase angles, damping, and oscillation modes, derived from the phasor measurements and the other power system data sources in which the metrics are indicative of events, grid stress, and/or grid instability, over the wide area;
>
> displaying the event analysis results and diagnoses of events and associated ones of the metrics from different categories of data and the derived metrics in visuals, tables, charts, or combinations thereof, the data comprising at least one of monitoring data, tracking data, historical data, prediction data, and summary data;
>
> displaying concurrent visualization of measurements from the data streams and the dynamic stability metrics directed to the wide area of the interconnected electric power grid;
>
> accumulating and updating the measurements from the data streams and the dynamic stability metrics, grid data, and non-grid data in real time as to wide area and local area portions of the interconnected electric power grid; and
>
> deriving a composite indicator of reliability that is an indicator of power grid vulnerability and is derived from a combination of one or more real time measurements or computations of measurements from the data streams and the dynamic stability metrics covering the wide area as well as non-power grid data received from the non-grid data source.

A216 at 30:66–A217 at 31:52. The remaining asserted claims of the Patents-in-Suit further recite other substantial and concrete solutions for wide-area, real-time monitoring of an electric power grid. *See*, *e.g.*, A156 at 29:59–30:24.

1. The ". . . interface for receiving a plurality of data streams . . ." Limitations Recite a Specific, Concrete Type of Streaming Raw Data

The Patents-in-Suit are directed to a system that receives a specific type of data, called streaming synchronized phasor data. Such data is collected at geographically distinct points over a wide area of the grid. Phasor measurements, taken by phasor measurement units ("PMUs"), can provide integrated voltage, current, frequency and phase measurements of the transmitted electricity at a specific part of the power grid. A6970. These measurements are generally taken at a rate of 30 or 60 measurements per second. *Id*. PMUs also receive a GPS time signal that is used to time stamp the measurements. *Id*. Phasor measurements taken at different parts of the power grid by different PMUs are then synchronized with one another by phasor data concentrators ("PDCs") based on the time stamp of each signal and are passed onto a monitor computer. *Id*.

The streaming phasor measurements are received by the monitor computer at a sub-second rate, 30 or 60 measurements per second. This data is incomprehensible to a human. A4873-74 ¶¶35-37. Even one stream of sub-second phasor data would prove too much for a human to comprehend, let alone multiple sub-second streams. A4873 ¶¶34-35.

The following screenshot shows the raw data PMU feeds:

3 StreamReader application showingstrip chart display

A3076.

Phasor data—as taught by the Patents-in-Suit—is most useful when correlated and compared against other measurements taken at or near the same instant. A146 at 9:26–44; A4873. While the frequency of electrical current at a point on the power grid at any given instant may provide valuable information as to the stability of that single point on the grid[4] (A3982–83 and A4873 ¶36), a single current or voltage phasor measurement, viewed in isolation, provides little information to an operator about the dynamic stability of local and wide area sections of the grid. *Id.* In order for phasor measurements to be exploited to their

[4] Deviations in frequency from 60Hz can indicate that the power grid is under stress.

maximum potential, the Patents-in-Suit recognize that measurements should be taken at different (and distant) points on the power grid, and correlated and compared against one other. A4873.

The Patents-in-Suit describe receiving raw synchrophasor data over a wide area of the electric power grid. A95 at 31:3–8; A155 at 28:16–30; and A217 at 31:3–11. The various asserted claims further recite receiving data from different areas and/or entities (such as different control areas in claim 1 of the ’843 Patent) and different entities (such as transmission companies, utilities and regional reliability coordinators, in claim 1 of the ’259 Patent). A95 at 31:3–8 and A155 at 28:16–30. To the extent prior art monitoring systems only received slow moving SCADA data from within an entity’s own footprint, the specific implementation of a system capable of receiving and characterizing specifically identified data over a wide area represents a substantial and concrete improvement in the art. A95 at 31:3–8; A155 at 28:16–30; A217 at 31:3–11; A4875.

2. The “deriving in real-time from the plurality of data streams . . .” Limitations Recite a Narrow Subset of Specific Enumerated Derived Metrics

Received sub-second phasor measurements streams are humanly incomprehensible. The systems and methods of the Patents-in-Suit derive specific dynamic stability metrics from the received data using known formulations and algorithms. A155 at 28:31–39 and A217 at 31:17–30. There are many metrics

available to examine the performance of the grid. The claims of the '259 Patent recite a narrow subset of <u>four</u> specifically enumerated derived dynamic stability metrics, namely: (1) phase angles, (2) damping, (3) oscillation modes, and (4) sensitivities.[5] A156 at 30:3-5. The derivation of metrics, according to the Patents-in-Suit, transforms the incomprehensible synchrophasor streams into humanly comprehensible metrics. *See* A4871 ¶30. For example, phase angle differences, derived from the comparison of two phase angle measurements taken at the same time at different parts of the power grid, inform an operator when the grid is under stress. A156 at 30:6–9 and 52–58. The asserted claims of the Patents-in-Suit recite these very specific metrics to shed light on instantaneous differences in values taken at disbursed points of the grid to provide instantaneous real-time insight into the dynamic (transient) state of the grid. *See* A4871 ¶30.

While these derived metrics may provide easier-to-understand information regarding the dynamic state of the power grid, operators can still be quickly inundated by the volume of these metrics and suffer from data overwhelm. This is particularly true when large numbers of generalized metrics are derived and streamed from multiple synchrophasor streams taken over a wide-area of the grid. *See* A4871 and A4873. Unlike prior art systems that focused on snapshot

[5] The claims of the '710 Patent recite three additional metrics derived from the synchrophasor streams, including frequency instability, voltages and power flows. A217 at 31:17-29.

measurements, however, the asserted claims of the Patents-in-Suit expressly focus on a very small subset of metrics (i.e., phase angles, damping, oscillation modes, and sensitivities) derived from the synchrophasor data that characterize the "dynamic stability" of the grid. The dynamic stability of the grid is a term of art that refers to the ability of the grid to remain interconnected (i.e., return to a stable state after an event or disturbance) and operate in synchronism following a real-time, subsecond disturbance. A4883–84 ¶71.

3. The "receiving data from other power system data sources . . ." Limitations Recite Specific Types of Grid and Non-Grid Sources from which the Data is Retrieved

The asserted claims of the Patents-in-Suit recognize, however, that phasor measurements and derived dynamic stability metrics alone may not provide sufficient situational awareness for operators to recognize and react to grid instability. A146 at 9:53–66. According to the asserted claims, the monitor computer, therefore, receives data from other power system data sources, such as transmission maps, power plant locations and traditional EMS/SCADA data, as well as information from non-grid sources (such as weather maps) to provide the operator with enhanced system operation visibility through multiple overlays of such data. A215 at 28:34–37 and 31:13–16.

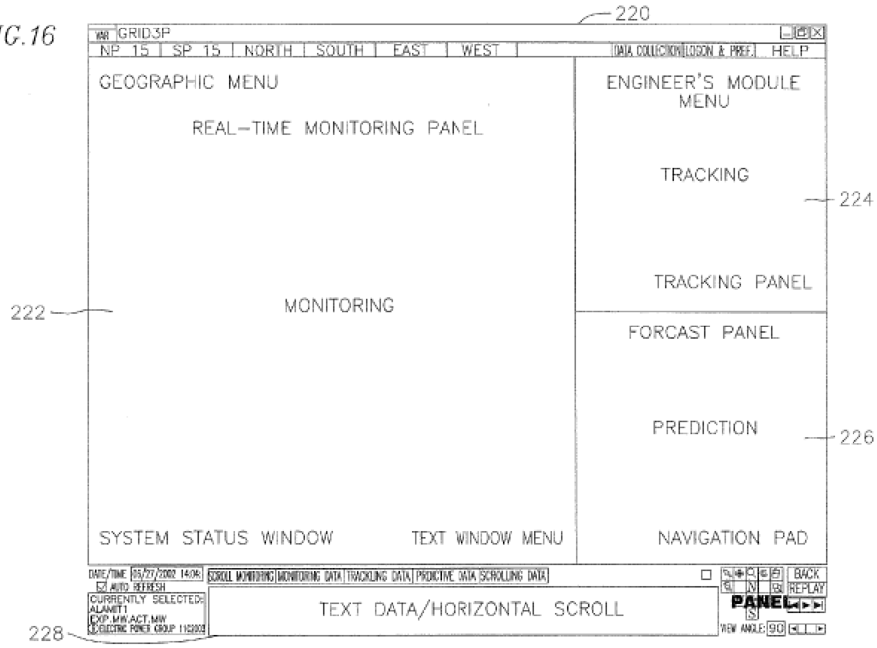
4. The "displaying concurrent visualization of measurements from the data streams and the dynamic stability metrics directed to the wide area of the interconnected electric power grid" Limitations Provide a Substantial and Concrete User Interface

To mitigate the occurrence of data overwhelm situations as described above, the asserted claims of the Patents-in-Suit still further recite concrete and tangible display features that delineate how the derived metrics and measurements are to be presented to an operator. A119–130; A132; A134; A137–141; A146 at 9:53–66 and A154 at 25:28–31. Claim 12 of the '710 Patent, for example, recites: "displaying . . . the different categories of data and the derived metrics in visuals, tables, charts, or combinations thereof, the data comprising at least one of monitoring data, tracking data, historical data, prediction data, and summary data" and "displaying concurrent visualization of measurements from the data streams and the dynamic stability metrics directed to the wide area of the interconnected electric power grid" A217 at 31:36–39. The remaining asserted claims also recite specific graphical user interfaces and concrete and tangible elements of the user interface. *See*, *e.g.*, claim 9 of the '843 Patent, A97 at 29:66–30:3 ("the monitor concurrently displays at least one dynamic geographic display and a plurality of data or text panels for at least one of monitoring, tracking, prediction, actions or mitigations"); claim 1 of the '259 Patent, A155 at 28:48–50 ("a graphical user interface provid[ing] concurrent visualization of a plurality of metrics directed to a

wide geographic area of the grid"); claim 21 of the '259 Patent, A156 at 30:35–37 ("drilling down or zooming in and viewing data across the metrics and across the geographically distinct points").

Examples of the claimed concurrent visualization techniques are provided throughout the specification. The specification states that "Layer 3 (7) uses a novel visualization system that includes a multi-layer view for geo-graphic, wide and local areas. Such a system that allows local or wide area visualization provides significant benefits for understanding the effect of national or neighborhood areas on local areas [of] interest, such as local utilities." A146 at 9:53-58. FIG. 16 of the Patents-in-Suit (below) shows an exemplary conceptual outline for the concurrent visualization user interface. The exemplary interface, among other elements, includes a real-time monitoring panel having geographic, grid and non-grid data overlays juxtaposed with specifically identified associated panels for presenting tracking, prediction and scrolling raw data feeds.

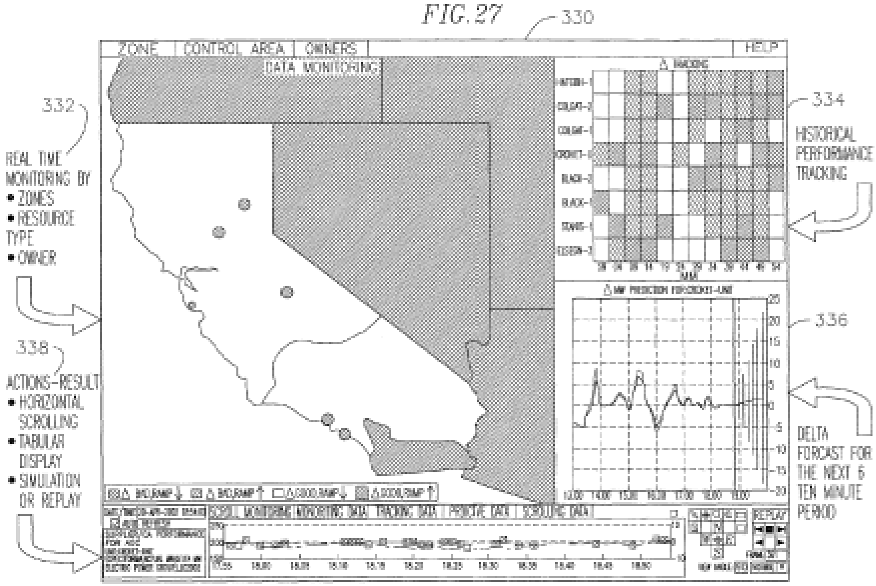
FIG.16



A179 (Figure 16 of the Patents-in-Suit).

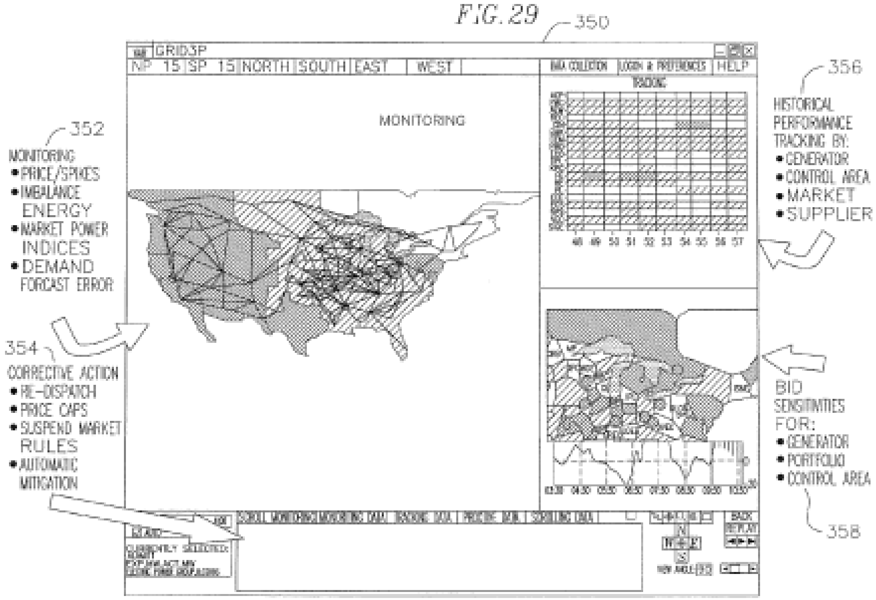
Furthermore, the Patents-in-Suit include multiple figures illustrating exemplary embodiments of many of the recited concurrent visualization features, two of which are reproduced below. *See also* A119–29; A134; and A137–41.

FIG. 27



A130 (Figure 27 of the Patents-in-Suit).

FIG. 29



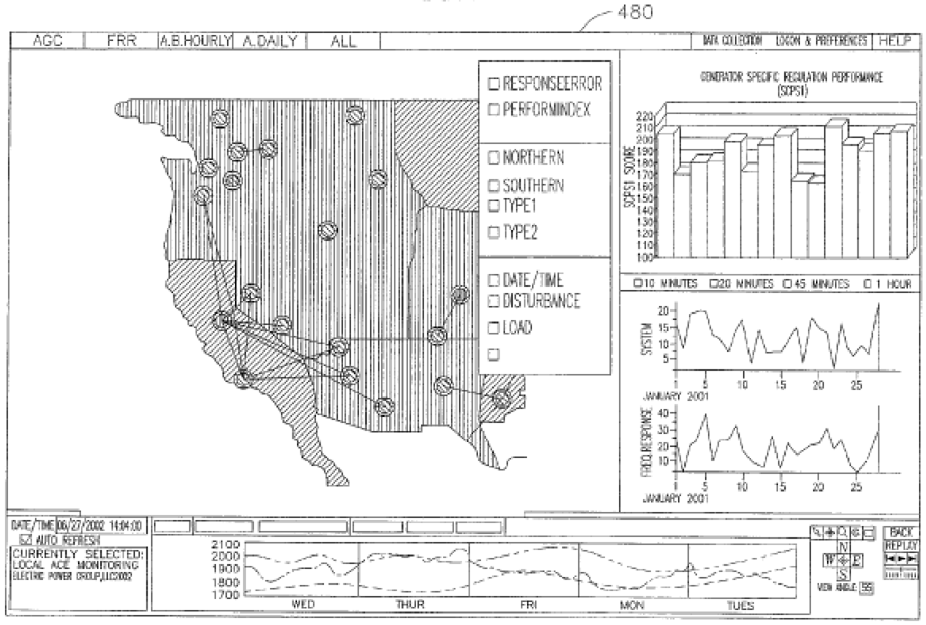
A132 (Figure 29 of the Patents-in-Suit).

The asserted claims transform the derived metrics from mere numbers into graphical and geographic displays containing multiple overlays and multiple panels concurrently providing changing monitoring data and tracking data. A146 at 9:53-58. Through this transformation and concurrent visualization, the system provides operators with the ability to quickly interpret massive amounts of otherwise incomprehensible information. *Id.* The graphical user interface includes a combination of a geographic display and data or text panels. A146 at 9:58–63 and 10:16–25 and A148 at 14:10–17. The geographic display allows an operator to quickly determine the location of a measurement. *Id.* The data or text panels, as one example, concurrently display information relating to a particular measurement viewed on the geographic display. *Id.* For example, the data or text

panel may show a histogram of a particular measurement source (such as a PMU), allowing an operator to quickly and accurately determine any trends as to the state of the power grid at a particular point, both geographically and temporally. A119; A122; A124; A126; A129; A130; A132; A134; and A138–41.

The claimed concurrent visualizations quickly let an operator know the location of a measurement or fault simply by looking at the map itself. As shown in FIG. 37, reproduced below, the operator may then drill down onto remote control areas outside of his or her control area to pinpoint the location of a fault and monitor the performance of generators and other electrical components that may be affected. Among massive amounts of data, this feature allows the operator to readily become aware of the severity of remote faults, and their potential effect on components and subsystems in the operator's own control area. A146 at 10:56–62 and A156 at 29:33–37.

FIG. 37



A200 (Figure 37 of the Patents-in-Suit).

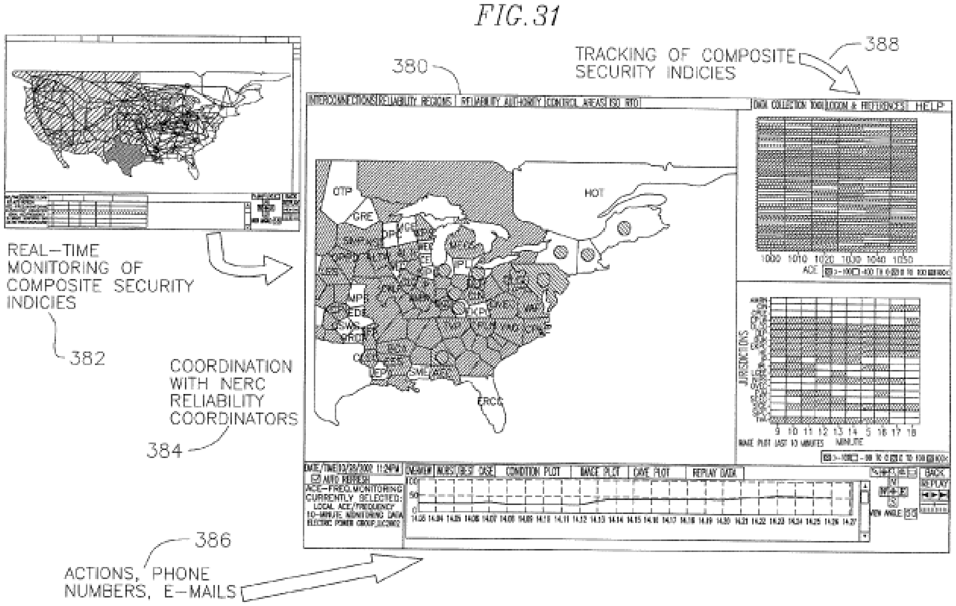
Immersed within the interface, the operator may concurrently use the same interface to review tracking data, historical data and raw data feeds that provide further context to the operator of the severity of the disturbance, and whether and where intervention is required to prevent a fault from cascading through his or her control area. *Id.*

5. The Composite Indicator of Reliability and Other Alarm Threshold Limitations

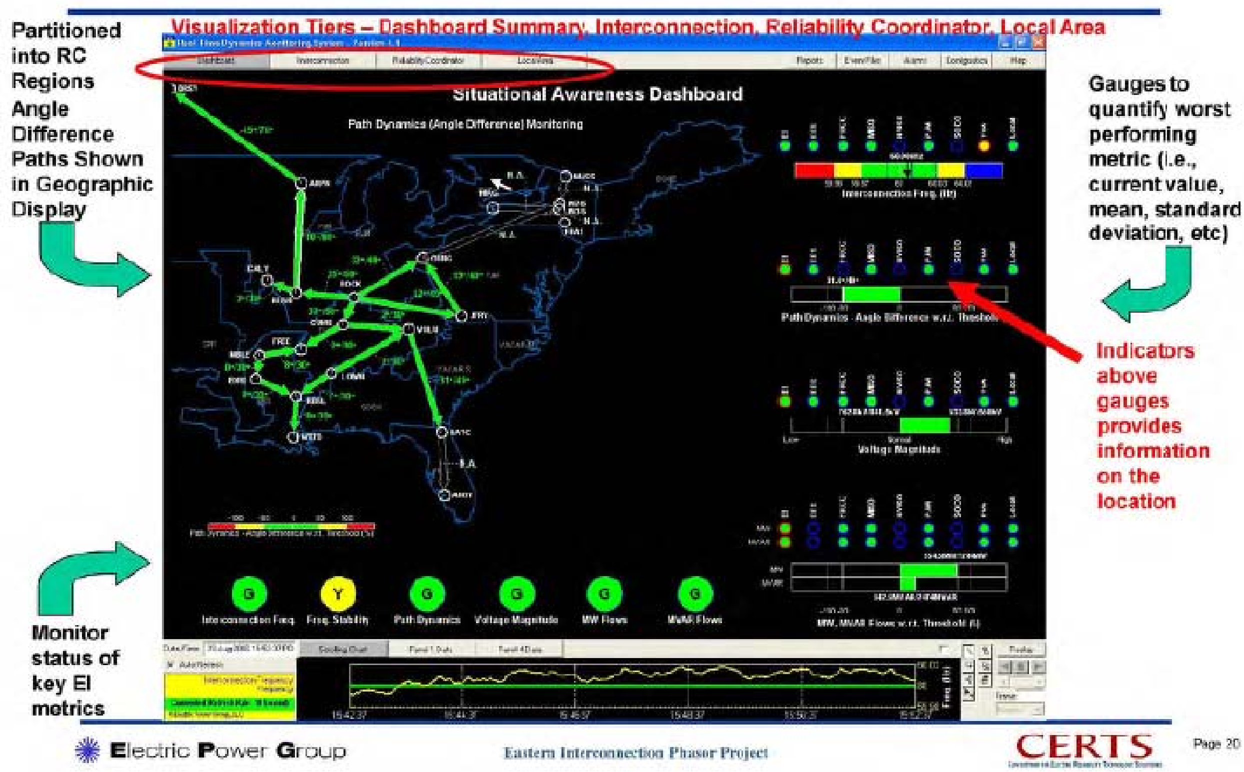
To further enhance situational awareness, the system provides composite indicators of reliability engrafted within the concurrent visualization interface to assist the operator in understanding conditions that are contributing to potential vulnerability of the grid, such as color coded alerts based on grid data and non-grid

data. A150 at 17:23-30 and A210 at 17:27-34. For example, the exemplary embodiment depicted in FIG. 31 (below) includes color coded security indices displayed in conjunction with streaming data and geographic displays. A194; A5003. The system also monitors the vulnerability of the grid by providing alarms when the monitored data crosses certain thresholds or is in proximity to interconnected power plants or population centers, further providing real-time situational awareness to the operator. *See*, *e.g.*, A155 at 28:61–67.

FIG. 31



A134 (Figure 31 of the Patents-in-Suit). The following figure is a color screenshot from EPG's commercial RTMS system (A5002) that incorporates the features of the Patents-in-Suit and depicts color coded indices on the real-time display itself.



Taken individually and as a whole, the patented systems and methods provide substantial and concrete tools that enable operators to more efficiently monitor and manage large power grids with geographically disbursed generators and loads while also reducing the occurrences of costly blackouts. A144 at 6:9–30 and A146 at 9:53–64.

IV. THE SUMMARY JUDGMENT PROCEEDINGS

In November 2014, following the close of fact and expert discovery, the parties brought cross-motions for summary judgment. A2732-65; A2869-70. Among other motions, EPG brought a motion for summary judgment of direct

infringement as well as a motion to exclude the opinions of Ms. Virginia Lee, who purported to provide expert testimony.[6] A3324-52; A2844-68.

Among other motions, Defendants brought a motion for summary judgment of non-infringement and invalidity. A2732-50. <u>Defendants did not submit any expert testimony from Ms. Lee or any other expert in support of their motion.</u> A2734.

In contrast, EPG opposed Defendants' motion for summary judgment with a brief (A4773-91) and the testimony of its technical expert, Mr. Terry Winter (A4865-904; A4955-68; A4991-5071; A5524-56; A6065-86). Mr. Winter has vast experience in the fields of power grid monitoring. Mr. Winter spent over 20 years overseeing power operations for San Diego Gas & Electric and was responsible for the generation and transmission aspects of the business. A4866-67; A4890-94. Mr. Winter also served as COO and CEO of California Independent System Operator ("CAISO"), the entity responsible for managing California's power grid operations. A4866. CAISO monitors, manages, and ensures reliability of the power grid to prevent interruptions and blackouts. *Id.* For many years, Mr. Winter oversaw control rooms housed with operators tasked with electric power grid

[6] EPG's motion to exclude the testimony of Ms. Lee was premised upon the fact that: (i) she had no understanding of the meaning of multiple claim terms and their significance to the scope of the claims; (ii) she also had little to no experience in the field of real-time power grid monitoring; and (iii) she was not equipped to competently provide testimony from the standpoint of one skilled in the art. In short, Ms. Lee was no expert at all.

monitoring and was part of the panel of experts assembled in 2003 to review the cause of the catastrophic August 14, 2003 blackout. A4867 ¶47.

Defendants premised their § 101 argument on a myriad of district court cases holding various patents on wholly dissimilar technologies and solutions to be ineligible. Defendants' cited cases involved patents directed to long-practiced business practices and methods of organizing human activity, such as meal planning, match-making, hedge fund planning, bingo gaming and document management and retrieval.[7] A6984-88; A2740; A2745. Defendants trivialized and ignored multiple features of the asserted claims.[8]

Defendants articulated the alleged abstract idea embodied in the asserted claims in several different ways, including the following:

(1) "monitoring the power grid via receiving, storing, and display data in a ubiquitous computerized environment" (A2744 at 13–15);

(2) "a real-time systems used data from a wide-area network" (*Id*. at 24–25);

(3) "real-time, wide-area power grid monitoring" (A6449 at 5–6);

[7] Following the initial briefing, Defendants filed supplemental briefing analogizing EPG's claims directed to cases involving real-time document retrieval and real-time recommendations for tourist attractions. A6984-88. EPG filed objections to the supplemental briefing. A7180-87.

[8] By way of one example, Defendants asserted that EPG's claimed concurrent visualization interface amounted to nothing more than the generic display showing static photographs of food set forth in *DietGoal Innovations LLC v. Bravo Media LLC*, 33 F. Supp.3 d 271 (S.D.N.Y. July 8, 2014). A2746.

(4) "real-time, wide-area system" (A6451 at 20); and

(5) "a real-time system" (A6452 at 4).

Over six months after the initial briefing was submitted, the district court in May 2015 granted Defendants' motion for summary judgment of invalidity under § 101, and denied all of the other pending motions as moot. A23. The district court began its opinion by providing a self-styled "technical background" in which it cited to a single paragraph of the Background section of the Patents-in-Suit. A24.

In its analysis, the district court focused on asserted claim 12 of the '710 patent, which it proclaimed exemplifies the "general concept" claimed by the patents. A26-27. Citing to *Ultramercial, Inc. v. Hulu*, LLC, 772 F.3d 709, 715 (Fed. Cir. 2014), *cert. denied*, 135 S. Ct. 2907 (2015), the district court declared that the "concept embodied in a majority of the limitations" reduces to eight conceptual elements. A27. Each of the listed elements excluded a number of claim elements. By way of example, the following chart illustrates how the district court reduced some of the actual limitations to conceptual elements:

Limitation from claim 12 of the '710 Patent	District court's conceptual summary
receiving a plurality of data streams, each of the data streams comprising sub-second, time stamped synchronized phasor measurements wherein the measurements in each stream are collected in real time at geographically distinct points over the wide area of the	receiving data from different parts of an electric power grid

interconnected electric power grid, the wide area comprising at least two elements from among control areas, transmission companies, utilities, regional reliability coordinators, and reliability jurisdictions	
detecting and analyzing events in real-time from the plurality of data streams from the wide area based on at least one of limits, sensitivities and rates of change for one or more measurements from the data streams and dynamic stability metrics derived from analysis of the measurements from the data streams including at least one of frequency instability, voltages, power flows, phase angles, damping, and oscillation modes, derived from the phasor measurements and the other power system data sources in which the metrics are indicative of events, grid stress, and/or grid instability, over the wide area	Detecting and analyzing events in real-time from the data sources
displaying concurrent visualization of measurements from the data streams and the dynamic stability metrics directed to the wide area of the interconnected electric power grid	Displaying a visualization of the data received

The district court articulated the alleged abstract idea in the following different ways, each of which differed from Defendants' various characterizations:

(1) "monitoring and analyzing data from multiple sources simultaneously" (A26);

(2) "collecting, analyzing, and displaying data from multiple sources simultaneously" (A27); and

(3) "monitoring and analyzing data from disparate sources" (*Id.*); and

(4) "monitor[ing] data from multiple sources across an electric power grid" (A30).

In addition to its over-simplification of the recited complexities of the asserted claims, the district court's purported analysis of step two of the *Alice/Mayo* test did not even discuss each of its distilled elements. A27-30. For example, the district court wholly disregarded conceptual elements 1 through 3. *Id.* The district court acknowledged that the recitation of enumerated metrics "does limit the claim's scope," but then made the blanket conclusory finding that the enumerated metrics are "simply routine and conventional metrics." A28. The district court summarily dismissed as "post solution activity" all of the limitations directed to receiving particular grid and non-grid data and providing a concurrent visualization user interface without discussion or support of the same. A28-29.

At no point did the district court provide a scintilla of a claim construction in its order, nor did it cite to the expert testimony of EPG's expert, Terry Winter, except to dismiss it as being directed to a legal conclusion. A27.

SUMMARY OF THE ARGUMENT

The asserted claims satisfy both steps of the *Alice/Mayo* test, and are therefore patent eligible. The claimed systems and methods overcome problems presented by real-time monitoring of wide areas of the electric power grid by receiving a specific type of sub-second human-incomprehensible data and performing two transformations on the data, thereby alleviating the effects of data overwhelm. The claimed concurrent visualization interface additionally prevents data overwhelm through characterization of the performance of wide areas of the electric power grid in real-time using overlays and juxtaposed panels of specifically delineated grid and non-grid information. In so doing, the patented systems and methods enable an operator in one control area to become situationally aware of transient events in other control areas and take evasive action before disturbances from neighboring jurisdictions propagate and cascade into uncontrollable power failures.

In concluding that the asserted claims are patent ineligible, the district court erred by distilling and overly generalizing claim 12 of the ’710 Patent into eight isolated “conceptual elements.” In doing so, the district court stripped the claim of essential elements and ignored the interaction of the elements as an ordered combination. For example, the court did not address the plural streams of humanly incomprehensible raw data received by the system, failed to appreciate the

significance of the system's transformation of the raw data into a narrow subset of particularly enumerated metrics that represent the dynamic stability of the grid, and equated the concurrent visualization user interface and all of its specifically claimed features to a generic "display."

The district court also failed to coherently describe the abstract idea, presenting several different versions of the alleged idea. Each of the court's characterizations is overly generalized and fails to take into account any of the substantial and concrete limitations of the asserted claims.

In analyzing the second step of the *Alice/Mayo* framework, the district court also dismissed several of its own stripped down "conceptual elements," including the one concerning the concurrent visualization interface, as being directed to insignificant post solution activity. In making these findings on summary judgment, the court did not cite to any evidence, conducted no claim construction and dismissed uncontroverted expert analysis submitted by EPG.

The district court additionally erred in finding that the asserted claims grant a monopoly on "every potential solution" for monitoring data from multiple sources across an electric power grid. There are many monitoring systems that exist today that are commonly used for wide area monitoring. There is no risk of pre-emption in this case, given the specific claim limitations and the recited ordered combination of features.

STANDARD OF REVIEW

This Court reviews "summary judgment decisions under regional circuit law." *Brilliant Instruments, Inc. v. GuideTech, LLC*, 707 F.3d 1342, 1344 (Fed. Cir. 2013) (citation omitted). In the Ninth Circuit, a grant of summary judgment is reviewed *de novo* with the evidence viewed "in the light most favorable to the nonmoving party." *Toguchi v. Chung*, 391 F.3d 1051, 1056 (9th Cir. 2004).

The Federal Circuit applies its "own law, however, with respect to issues of substantive patent law. Patent eligibility under § 101 presents an issue of law that we review *de novo*." *Accenture Global Servs. v. Guidewire Software, Inc.*, 728 F.3d 1336, 1340–1341 (Fed. Cir. 2013) (citations omitted).

ARGUMENT

There is a stark contrast between unpatentable claims that preempt all uses of an abstract idea and patentable claims drawn to solutions of real-world problems that provide improvements to an actual technology or technical field. The asserted claims of the Patents-in-Suit unquestionably fall into the latter camp.

I. SUMMARY JUDGMENT WAS IMPROPER BECAUSE THE ASSERTED CLAIMS SATISFY THE TWO-STEP TEST FOR PATENT ELIGIBILITY UNDER 35 U.S.C. § 101 AS SET FORTH IN *MAYO* AND *ALICE*.

In both *Mayo* and *Alice*, the Supreme Court compellingly distinguished between two categories of claims—those directed to the basic "building block[s] of human ingenuity" and those that "integrate the basic building blocks into something more," thereby transforming the claims into patent-eligible inventions. *Alice Corp. Pty. Ltd. v. CLS Bank Int'l*, 134 S. Ct. 2347, 2354 (2014) (citing *Mayo Collaborative Servs. v. Prometheus Labs., Inc.*, 132 S. Ct. 1289, 1301 (2012)). Patent claims directed to the first category—the building blocks of human ingenuity—"effectively grant a monopoly" over the abstract idea itself and risk pre-empting public access to the idea. *Id.* Patent claims directed to the second category, including those claims encompassing "new and useful" applications of abstract ideas, pose no comparable risk of pre-emption and are therefore patent eligible. *Id.*

To delineate between these two realms, a "framework for distinguishing patents that claim . . . abstract ideas from those that claim patent-eligible applications of those concepts" was conceived. *Alice*, 134 S. Ct. at 2355 (citing *Mayo*, 132 S. Ct. at 1289). First, the court must determine "whether the claims at issue are directed to" an abstract idea. *Id.* If the court determines that the claims are not directed to an abstract idea, the inquiry ends and the claims must be upheld. *Id*. Only if the court determines that the claims are directed to an abstract idea, then the court must "consider the elements of each claim both individually and as an ordered combination to determine whether the additional elements transform the nature of the claim into a patent-eligible application." *Id.* (internal citation and quotations omitted). In viewing the claims as a whole, the Supreme Court specifically sought to identify whether the challenged claims "effect an improvement in any other technology or technical field." *Id.* at 2359.

In advancing this framework, the Supreme Court explicitly stated that courts must "tread carefully in construing this exclusionary principle lest it swallow all of patent law" as "[at] some level, all inventions . . . embody, use, reflect, rest upon, or apply laws of nature, natural phenomena, or abstract ideas." *Id.* (internal citation and quotations omitted). But the mere involvement of an abstract concept does not necessarily strip a claim of patent eligibility; the application of an abstract idea nevertheless remains eligible for patent protection. *Id.*

A. **<u>Step One: The Asserted Claims of the Patents-in-Suit Are Not Directed to an Abstract Idea, and Thus Constitute Eligible Subject Matter</u>**

The court must decide "whether the claims at issue are directed to a patent-ineligible" abstract idea. *Alice*, 134 S. Ct. at 2355.

1. The Asserted Claims are Not Directed to an Abstract Idea

Here, the asserted claims pass the first step and this Court need not go further. The asserted claims include substantial and concrete limitations that, as a whole, provide a real-time monitor for the electric power grid. The claimed systems and methods are a concrete and tangible solution to the problem of how to monitor a wide area of the electric power grid in real-time and how to convey massive amounts of incomprehensible data (resulting from the breadth and speed of the claimed type of real-time data).

More particularly, the claimed monitor, *inter alia*:

(1) receives multiple streams of particularly specified humanly incomprehensible, real-time, raw data measurements from geographically distinct points over a wide area of the grid;

(2) transforms the raw streaming data into multiple streams of particularly specified derived metrics (i.e., frequency instability, voltages, power flows, phase angles, damping, and oscillation modes) that are indicative of the dynamic stability of the grid (i.e., the ability of the grid to withstand disturbances and return to a stable operating state);

(3) receives other non-transient information, including grid and non-grid data (e.g., EMS/SCADA data, ACE/Frequency readings, Epsilon readings, power plant locations, transmission maps, geographic maps, interconnection maps); and

(4) further transforms the streaming metrics to present them in a "concurrent visualization" interface that overlays the streaming metrics with the grid and non-grid data and juxtaposes the overlays with panels that display additional information (e.g., monitoring data, tracking data and/or historical data) to characterize the performance of wide areas of the power grid and enable an operator to achieve situational awareness in real-time about destabilizing conditions outside of the operator's control area without causing data overwhelm.

In other words, a fair articulation of the idea embodied in the asserted claims is a real-time monitor for the electric power grid that receives multiple humanly incomprehensible, time stamped, sub-second synchrophasor streams from geographically distributed points over the grid, transforms the synchrophasor streams into a limited subset of specifically enumerated streaming metrics chosen to characterize the transient dynamic stability of the grid, and further transforms the streaming metrics into a "concurrent visualization" interface that engrafts the streaming metrics upon geographical overlays and overlays of specifically enumerated grid and non-grid data, and juxtaposes additional panels of accumulated tracking data, historical data and raw data for providing the operator with situational awareness of the transient dynamic stability of the electric power grid.

The claimed systems and methods are a concrete and tangible improvement specific to the power grid. Properly articulated, the asserted claims plainly are not directed to an abstract idea.

2. The Asserted Claims are Not Abstract Under a Line of Authority Specifically Addressing the Monitoring of Raw Data, and Transforming the Data to Characterize a Living Body

Nor are the asserted claims abstract under a long upheld line of authority specifically addressing the monitoring of raw data and transforming that data into a new form of comprehensible data. The asserted claims of the Patents-in-Suit include limitations that are far more substantial and concrete than those found to be patent eligible in a line of cases directed to monitoring applications, including *Arrhythmia Research Tech., Inc. v. Corazonix Corp.*, 958 F.2d 1053, 1059 (Fed. Cir. 1992) and *In re Abele*, 684 F.2d 902, 909 (C.C.P.A. 1982).

In *Arrhythmia Research*, the claimed method recited obtaining streaming electrocardiograph signals, transforming the received signals from analog to digital form, processing the digital signal using one of "several known procedures" and then comparing the output signal to a predetermined level to "indicat[e] whether the patient is at high risk for ventricular tachycardia." 958 F.2d at 1059. This Court found that the recited steps are "physical process steps that transform one physical, electrical signal into another" and that "**[t]hese input signals are not**

abstractions; they are related to the patient's heart function." *Id*. (emphasis added).

The asserted claims here go further than those in *Arrhythmia Research*, by *inter alia* receiving multiple different streaming measurements directed to the physical state of a machine, deriving specific enumerated dynamic stability metrics from the measurements, and providing a dynamic concurrent visualization of the physical state of the machine. *Arrhythmia Research* lacked any kind of display and was still found to be patent eligible.

The patent at issue in *In re Abele* included claims directed to an improved CAT-scan process. 684 F.2d at 903. In the claim found to be patent eligible, the final step of the CAT-scan process involved transforming the received raw data into a display, which the court found was a physical depiction of the scanned body part. *Id.* at 908-09. The court specifically pointed to the inclusion of the recited display features in deciding the eligibility of the claim. *Id.* Here, the claims are directed to a system that receives multiple streams of incomprehensible phasor data twice transforms the data, and presents a dynamic physical representation of the electric power grid, which is a "living" physical object. The claims here recite additional features describing how to particularly frame and present the information that are above and beyond the generic display recited in *In re Abele*.

This Court has found time and time again that "the transformation of [] raw data into a particular visual depiction of a physical object on a display [is] sufficient to render" a process patent-eligible. *In re Bilski*, 545 F.3d 943, 963 (Fed. Cir. 2008), *aff'd but criticized sub nom.*, *Bilski v. Kappos*, 561 U.S. 593 (2010) (citing *In re Abele*, 684 F.2d 902, 909 (C.C.P.A. 1982)); *see also*, *PerkinElmer, Inc. v. Intema Ltd.*, No. 2011–1577, 496 Fed. Appx. 65, 72 n.3 (Fed. Cir. Nov. 20, 2012) (discussing *In re Abele* and *In re Bilski*). In view of the detailed and concrete limitations of the asserted claims, the same result is warranted here.

3. Certain Limited Underpinnings of this Court's Opinion in *DDR Holdings* Support the Patent Eligibility of the Asserted Claims

The asserted claims are also patent eligible based on certain limited legal underpinnings of this Court's decision in *DDR Holdings, LLC v. Hotels.com, L.P.*, 773 F.3d 1245 (Fed. Cir. 2014). Both the present invention and the invention of *DDR Holdings* solve problems that are not "some routine business practice," such as hedge fund trading or advertising. *Id.* at 1257. In *DDR Holdings*, this Court found that even though the claims involved "both a computer and the Internet," the claims were nonetheless patent-eligible as they created a solution "necessarily rooted in computer technology in order to overcome a problem specifically arising in the realm of computer networks." *Id.* at 1257.

Here, the asserted claims are admittedly not Internet-centric, but do provide a solution to a problem specific to real-time monitoring of wide areas of the electric power grid. Further, the "concurrent visualization" interfaces here bear logical similarity to the hybrid website interfaces in *DDR Holdings*, in that neither are generic displays, but serve to solve specific, concrete problems.

4. The Asserted Claims Are Not Directed to Abstract Mental Processes

The claimed monitor computer is an indispensable part of the claimed systems. "[T]o impart patent-eligibility to an otherwise unpatentable process under the theory that the process is linked to a machine, . . . the machine must play a significant part in permitting the claimed method to be performed." *CyberSource Corp. v. Retail Decisions, Inc.*, 654 F.3d 1366, 1375 (Fed. Cir. 2011) (citations omitted). For this, "a computer must be integral to the claimed invention, facilitating the process in a way that a person making calculations or computations could not." *Bancorp Servs., L.L.C. v. Sun Life Assur. Co. of Canada*, 687 F.3d 1266, 1278 (Fed. Cir. 2012) (*cert. denied*, 134 S. Ct. 2870 (2014)). This is seen, for instance, where the machine performs methods that cannot be performed entirely in the human mind. *See SiRF Tech., Inc. v. Int'l Trade Comm'n*, 601 F.3d 1319, 1333 (Fed. Cir. 2010); *see also Helios Software, LLC v. SpectorSoft Corp.*, C.A. No. 12-081-LPS, 2014 WL 4796111 at *17 (D. Del. Sept. 18, 2014) (post-*Alice Corp.* decision; claims including "real-time data capture and transmission

and reception" necessitated a computer "to play a significant part in permitting the claimed method to be performed" since "none of these limitations could be performed by a human alone").

The asserted claims are not directed to abstract mental processes that could be performed in a human mind. A human being could not comprehend the flow of streaming data at any stage of the claimed invention. It is impossible for a human being to comprehend and correlate data streaming from multiple locations at 60 Hz (i.e., 60 times per second). The flow of phasor data being monitored is incomprehensible to a human, and would constitute a blur of information to a person viewing the raw data. The fact that a human being cannot possibly perform any of the claimed steps is evidence that the claims are not drawn to an abstract idea.[9]

The monitor computer in the asserted claims is limited by the types of specialized data it receives, including multiple incomprehensible streams of time-

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[9] The asserted claims are distinguishable from claims found to be directed to patent-ineligible abstract concepts that could be performed in the human mind. See, e.g., *CertusView Techs., LLC v. S & N Locating Servs., LLC*, No. 2:13cv346, 2015 WL 269427, at *19 (E.D. Va. Jan. 21, 2015) (computerized method of creating paper manifests); *In re TLI Communications LLC Patent Litigation*, MDL No. 1:14md2534, 2015 WL 627858, at *13 (E.D. Va. Feb. 6, 2015) (computerized categorization of photographs); *Joao Bock Transactions Systems, LLC v. Jack Henry & Assocs., Inc.*, 76 F. Supp. 3d 513, 522 (D. Del. Dec. 15, 2014) (computerized system to withhold payment of a check); and *DietGoal Innovations LLC v. Bravo Media LLC*, 33 F. Supp. 3d 271, 283 (S.D.N.Y. 2014) (computerized meal planning).

stamped, sub-second time synchrophasor data collected from various portions of the grid. As such, the asserted claims could not be practiced by a human without computer aid, and the recited computer plays a significant part in allowing the claimed system to operate. A human simply could not perform the complex processes covered by the asserted claims, let alone visualize the resulting streaming metrics. Further, this is not a case where the computer simply facilitates the accomplishment of an abstract business practice. The monitor is part and parcel of the electric power grid, which is widely appreciated to be the largest machine in the world. The addition of the recited monitor computer, with its synchrophasor interfaces, thus plays a significant role in allowing the claimed methods to be performed, acting to "tie down" the claims to a specific computerized configuration rather than a superfluous generic suggestion.

Based on the foregoing, the asserted claims of the Patents-in-Suit are not directed to an abstract idea, or any other judicially created exception to patent eligibility.

B. Step Two: The Asserted Claims Recite "Significantly More" and are Patent Eligible under the Second Step of the *Alice/Mayo* Framework, Further Highlighting the District Court's Error

As the claims at issue are not directed to an abstract idea, the Court need not go beyond step one of the *Alice/Mayo* framework. Further highlighting the patent eligibility of the presently claimed inventions, reversal is independently

appropriate because the asserted claims "contain[] an inventive concept sufficient to transform the claimed abstract idea into a patent-eligible application." *Alice*, 134 S. Ct. at 2357 (internal quotations omitted). Step two of the *Alice/Mayo* framework has been described "as a search for an 'inventive concept'" and the Court is to "consider the elements of each claim both individually and 'as an ordered combination.'" *Id*. at 2355. The Court need not search far as that inventive concept is plainly and expressly recited in the asserted claims.

1. The Asserted Claims are Directed to an Ordered Combination of Elements That Together Solve a Particular Problem in the Art

When viewed "as an ordered combination," as is called for by the Supreme Court in *Alice*, the claims provide a technological advance in the area of monitoring systems and methods for the electric power grid and are significantly more than a mere drafting exercise which monopolizes any underlying idea. 134 S. Ct. at 2359. The claims at issue include precisely the "additional features" that the *Alice* and *Mayo* courts required to ensure that the claims are "more than a drafting effort designed to monopolize the [abstract idea] . . . . [by] simply stat[ing] the [abstract idea] while adding the words 'apply it.'" *Id.* (citation omitted).

Prior to the improvements recited in the asserted claims and disclosed in the Patents-in-Suit, there was "no single integrated system that can be used to monitor and manage the electric power grid in real-time across all of the different elements

of the power system." A142 at 2:5-8. Prior measurement-based systems could only be efficiently used to monitor local areas of the grid as the enormous amount of rapidly-changing information otherwise led to data overwhelm. A4875-76 ¶¶ 45-47. Such measurement-based systems in 2003 were unable to meaningfully compare measurements across geographically distinct areas, critical to managing overall stability of wide areas of the grid. A4875 ¶47. Model-based systems in 2003 using time-delayed data (such as SCADA data) could only estimate the state of the grid. A4874 ¶39. Model-based systems of the time could not apprise operators of the dynamic state of the power grid in real time and were inherently capable of operating without state estimation over a wide area.

In contrast, the claimed system and methods as a whole provide a particular implementation and ordered combination of: receiving specific types of streaming raw data; transforming the raw data into specifically enumerated dynamic stability metrics; receiving other types of data, including specifically enumerated types of grid and non-grid data; and transforming the derived dynamic stability metrics once again to display them in a specific, tangible form for the operator to understand the implications of the raw data. The specific progression of claimed steps solves a problem in the field of power grid monitoring—how to achieve real-time, wide area monitoring and provide situational awareness to an operator without data overwhelm. The claimed sequence is an integral part of the solution

to the problem. The limitations of the claimed sequence stand in stark contrast to limitations of other hypothetical claims that can be practiced at any point of the claimed solution without consequence, such as the claimed activity log in *Ultramercial*. The claimed sequence in the asserted claims here includes steps that build upon each of the preceding steps in an ordered combination to solve the problem at hand.

The asserted claims here go even further, in that they are directed to a way to achieve monitoring at a transient level, i.e., to assess the dynamic stability of the grid. Any of the features alone is a sufficient "additional feature" which ensures the claims are patent-eligible. The claims, viewed both as a whole and as an ordered combination, constitute a technological advance in the field of the power grid monitoring, further ensuring patent-eligibility. Thus, the claims at issue "effect an improvement" in a technical field. *Alice*, 134 S. Ct. at 2359.

2. The Limitations of the Asserted Claims Include Meaningful Limitations that Remove Them from Being Directed to any Alleged Abstract Idea

The particularly claimed implementations provide the additional features, *i.e.*, the "something more," this Court found present in *DDR Holdings* and found lacking in *Ultramercial*. The patented systems and methods provide but one narrowly tailored and technologically specific solution. The asserted claims do not preempt all forms of power grid monitoring, instead providing one narrowly

tailored, specific solution. EPG's expert provided uncontroverted testimony that there are many practical systems for wide-area real-time monitoring, available and in use today, that are not foreclosed by the asserted claims. A4878-83 ¶¶57-70. Over 10 years after the priority date of the Patents-in-Suit, the use of SCADA data still represents the dominant form of power grid monitoring. A4874-76 ¶¶42-46; A4881 ¶65; A4883 ¶69. Advanced state estimation techniques have continued to be developed since 2003 that enable SCADA to be used to estimate conditions in real-time over a wide-area. A4873–75, A7327.

Furthermore, not even all practical forms of real-time measurement-based monitoring of the power grid are preempted. A4870 ¶28; A4878-79 ¶¶57-60; A4880-81 ¶¶64-66. For example, real-time monitoring systems using any one of many different types of raw data (e.g., VAR, ACE, frequency, voltage, power and a host of other individual components) are not preempted by the claim, nor are real-time monitoring systems using synchrophasor data which merely display the data using one-line diagrams. Even geographic and other interfaces that provide other visualizations are not foreclosed, so long as they do not include every one of the narrowly claimed features. By way of example, Defendants have stated that they have developed a system that includes the concurrent visualization features of the asserted claims, but relies solely on SCADA data and advanced algorithms to provide real-time, wide-area monitoring. A6246; A6370-71 at 93:7-94:13; A6372

at 308:18-309:24. Based on the foregoing, even if the Court finds that the asserted claims are directed to an abstract idea, the specific claim limitations, individually and as an ordered combination, are sufficient to render the claims patent eligible.

II. THE DISTRICT COURT ERRED IN ITS ANALYSIS OF THE *ALICE/MAYO* FRAMEWORK

A. <u>The District Court Erred in its Analysis of Step One of the *Alice/Mayo* Framework</u>

1. The District Court Improperly Read Into the Statements Contained in the Background Section of the Patents-in-Suit

The district court's analysis misinterprets the scope, capabilities, and operating principles of prior power grid monitoring systems. Throughout its decision, the district court relies heavily on faulty assumptions regarding what was conventional in the prior art and apparently relied upon a false extrapolation of the prior art power grid monitoring systems described in the Patents-in-Suit. *See* A24. In its order, the district court quoted a passage from the "Background of the Invention" describing the problem in the prior art of only local monitoring methods available to monitor the grid. *Id.* The district court then implicitly applied a false and unsupported extrapolation which assumes that the prior local monitoring systems and methods could be scaled up to provide real-time, wide-area monitoring. This is not the case.

2. The District Court Analysis Overly Generalized and Omitted Critical Limitations of the Asserted Claims

The district court continued its analysis by dissecting one representative claim into self-fashioned "conceptual elements" it alleged sets forth the "concept embodied by the majority of the limitations." A27. Based on these elements, the court found that the asserted claims are drawn to the differing abstract ideas of "monitoring and analyzing data from multiple sources simultaneously," "monitoring and analyzing data from disparate sources" or "monitor[ing] data from multiple sources across an electric power grid." A26; A27; and A30.

By distilling the claim into eight "conceptual elements," the district court stripped the claim of many specific, concrete features, essentially ensuring that the claim would be found to be directed to an abstract idea. *See*, *e.g.*, *SimpleAir, Inc. v. Google, Inc.*, No. 2:14-CV-00011-JRG, 2015 WL 5675281, at *4 (E.D. Tex. Sept. 25, 2015) ("The question before the Court, according to the Ineligible Concept Step of the Alice test, is not whether the Court is able [to] reach into a patent and extract an abstract idea from which to determine patent-eligibility; such an exercise would render the Ineligible Concept Step a mere formality."

For example, claim 12 of the '710 Patent recites, in part, "receiving a plurality of data streams, each of the data streams comprising sub-second, time stamped synchronized phasor measurements wherein the measurements in each stream are collected in real time at geographically distinct points." A217 at 31:3–

8. This limitation identifies the specific type, location, and rate of received data required to practice the limitation. The district court overly simplified this limitation into merely "receiving data from different parts of an electric power grid." A27. Even more egregiously, the district court failed to consider the transformative nature of the dynamic stability metrics features,[10] simplifying these features to "detecting and analyzing events in real-time from the data sources," reading out the specified recited features and therefore the substantive nature of the limitation. A27.

The district court relies on *Ultramercial* for its "conceptual analysis" test. A27 (citing *Ultramercial*, 772 F.3d at 715). However, this Court's analysis in *Ultramercial* differed significantly from the district court's "conceptual element" analysis. In *Ultramercial*, this Court merely distilled the steps of the claim by removing *superfluous* language while retaining the essence of various claims; it did not distill the steps into "conceptual elements" by reading out specific recited

[10] The relevant portion of claim 12 of the '710 Patent recites "detecting and analyzing events in real-time . . . from the data streams and ***dynamic stability metrics derived from analysis of the measurements from the data streams including at least one of frequency instability, voltages, power flows, phase angles, damping, and oscillation modes***." A217 at 31:18–25 (emphasis added).

features.[11] Fairly applying an *Ultramercial*-style analysis to the first step of claim 12 of the ’710 Patent results in receiving a plurality of sub-second, time stamped synchronized phasor measurements from distinct points of an electric power grid and from at least two entities, not merely “receiving data from different parts of an electric power grid.” A27. *See*, *e.g.*, *SimpleAir* at *3 (*citing Ultramercial*, 772 F.3d at 714–15) (“We first examine the claims because claims are the definition of what a patent is intended to cover.”)

3. Strongly Evidencing That the Asserted Claims Are Not Directed to an Abstract Idea, the Defendants and the District Court Provided Multiple Different Articulations of the Alleged Idea

Moreover, similar to *DDR Holdings*, in which the defendant provided numerous different characterizations of the alleged underlying abstract idea, 773 F.3d at 1256–57, both the Defendants and the district court failed here to articulate a single, consistent alleged abstract idea to which the claims are directed. Struggling mightily to account for the various concrete claim limitations, the Defendants variously characterized the alleged abstract idea to which the claims are directed <u>in at least five different ways</u>, including: (1) “monitoring the power grid via receiving, storing, and display data in a ubiquitous computerized

[11] For example, in *Ultramercial*, this Court distilled the recited step of “receiving, from a content provider, media products that are covered by intellectual property rights protection and are available for purchase” to “receiving copyrighted media from a content provider.” 772 F.3d at 712 and 714.

environment" (A2744 at 13–15); (2) "a real-time system using data from a wide-area network" (*Id.* at 24–26); (3) "real-time, wide-area power grid monitoring" (A6449 at 5–6 and 19); (4) "a real-time, wide-area system" (*Id.* at 2-3; A6451 at 20); and (5) "a real-time system" (A6452 at 4) (internal quotations omitted).

The district court similarly struggled to define a single, consistent alleged abstract idea. For example, the district court stated that: (1) "the asserted claims . . . are drawn to the abstract idea of monitoring and analyzing data from multiple sources simultaneously" (A26); (2) "the concept embodied by the majority of the limitations describes only the abstract idea of collecting, analyzing, and displaying data from multiple sources simultaneously" (A27); (3) "the claim is drawn to the abstract idea of monitoring and analyzing data from disparate sources" (*Id.*); and (4) "monitor[ing] data from multiple sources across an electric power grid" (A30). (internal quotations and citations omitted).

Not only did the district court fashion a different alleged abstract idea than any of the various characterizations provided by Defendants, its own characterization shifted throughout its holding. Such shifting characterizations are highly indicative that the claims are not directed to a patent-ineligible abstract idea, but instead provide concrete and tangible systems and methods beyond any reasonable level of abstraction. *DDR Holdings*, 773 F.3d at 1257; *see also Google, Inc. v. SimpleAir, Inc.*, No. CBM2014-00170, 2015 WL 331089 at *10 (P.T.A.B.

January 22, 2015), Paper 13 ("Petitioner's generalized arguments, not directed to the specific language of the challenged claims, are insufficient to show that the claims more likely than not are directed to a patent-ineligible abstract idea.")

4. The District Court Failed to Appreciate the Substantial and Concrete Application of the Patented Inventions

The so-called 'heart' of exemplary claim 12 of the '710 Patent is <u>not</u> an abstract idea and certainly not one so general as that at issue in *Ultramercial*. *See Ultramercial*, 772 F.3d at 714 (finding the core idea of the patent claim to be using advertising as currency). The asserted claims—at the very least—represent a "real-time, wide area monitoring system" for the United States electric power grid—"the largest, most complex machine in the world." A4780; *see also* A4869 at ¶20. Even the district court recognized that these "power systems are enormous and complex" and "the task of managing them is daunting." A24.

There is no abstract concept at issue. The asserted claims involve—at the least—data streams assembled from multiple locations at 60 times a second, phasor data that is incomprehensible to a human, and—absent the inventive and expressly claimed concurrent visualization—an assemblage of data that could not be perceived by any human being. *See* A4566-67; A4784-5.

Notwithstanding the evidentiary record—an evidentiary record that includes not conceptual theory but the ***evidenced real-world need*** for inventions such as those recited in the asserted claims—the district court nevertheless arrived at the

generalized conclusion that the claimed invention is nothing more than "monitoring and analyzing data from multiple sources simultaneously." A26. Such a conclusion constitutes the self-fulfilling prophecy of the Supreme Court's *Alice* decision: "we [must] tread carefully in construing this exclusionary principle lest it swallow all of patent law" as, "[a]t some level, 'all inventions . . . embody, use, reflect, rest upon, or apply laws of nature, natural phenomena, or abstract ideas.'" *Alice*, 134 S. Ct. at 2354 (quoting *Mayo*, 132 S. Ct. at 1293). But claim 12 of the '710 Patent does far more than "claim the 'buildin[g] block[s]' of human ingenuity" and this can be said of all of the asserted claims of the Patents-in-Suit. *Alice*, 134 S.Ct. at 2354 (quoting *Mayo*, 132 S. Ct. at 1303).

Accordingly, the district court's analysis of whether the asserted claims are directed to an abstract idea is flawed.

B. The District Court Erred in its Analysis of Step Two of the *Alice/Mayo* Framework

1. The District Court Re-Analyzed the Same Self-Enumerated "Conceptual Elements" for Step Two, Ensuring It Would Not Find "Significantly More"

At step two, the district court merely re-analyzed the same self-enumerated "conceptual elements" analyzed at step one, essentially ensuring that it would find nothing "significantly more" in the claims. *See* A28–29. While over-distillation of the claims is improper at step one, it is even more egregious to re-analyze the same distilled concepts at step two—when the court is tasked with "search[ing] for an

'inventive concept.'" *Alice*, 134 S. Ct. at 2355 (citation omitted). The district court failed to undertake any search for an "inventive concept," instead reverting back to analyzing the same "conceptual elements" it analyzed in step one. The district court therefore essentially ensured, without fair consideration, that the claims did not pass step two.[12]

2. The District Court Inappropriately Dismissed Multiple Limitations Integral to Solving the Problem as Routine Post-Solution Activity

In its step two analysis, the district court looked at "Conceptual limitations 4 through 8" and found them all to provide "insignificant" or "conventional and routine post-solution activity." *See* A28–29. Yet the lack of depth of the district court's analysis is clear. In analyzing "Limitation 6," for example, the district court found that "displaying a visualization of the data received [] is merely a recitation of insignificant post-solution activity, which can be accomplished using conventional methods." A29. This analysis fails to even consider the plain language of the claim, let alone the meaning of the claim language as would be understood by one of ordinary skill in the art. For example, overlaying the district court's distillation of "Limitation 6" with the actual claim language provides:

[12] The district court engaged in reductionism at its most extreme. Claim 12 of the '710 Patent—a claim originally expressed in more than 380 words—was reduced to less than 20% of that by the district court: no more than 67 words. *See* A27. This was not merely arriving at the so-called "concept embodied by the majority of the limitations" but a draconian evisceration of the heart and soul of claim 12.

"displaying concurrent [a] visualization of measurements from the data [received] streams and the dynamic stability metrics directed to the wide area of the interconnected electric power grid."[13] A39. Without considering claim language, the district court's conclusion—that this feature recites mere conventional post-solution activity—is unsurprising. For example, the district court alleges that "the claim language isn't limited to advanced visualizations" but failed to even consider the import of the "concurrent visualization" of derived dynamic stability metrics, instead distilling this feature to merely "displaying a visualization of the data received." A29.

The concurrent visualization disclosed and claimed in the Patents-in-Suit includes more than a generic display of raw data. As stated by EPG's expert, the claimed "advanced visualization features . . . provide and interpret monitored data in a meaningful way using overlaying, varying, and multi-panel displays which allow users to monitor and understand voluminous and rapidly changing information and were not available for real-time power grid monitoring systems prior to EPG's invention in 2003." A4871 ¶30; *see also*, *supra* Statement of the Case, Section III.B.4 (example embodiments of the recited "concurrent visualization" as illustrated in the Patents-in-Suit). The "concurrent visualization" disclosed and claimed in the Patents-in-Suit is a fundamental component of the

[13] Underlined text indicates claim language not considered by the district court and text in brackets indicates words added by the district court.

inventive solution. The claimed "concurrent visualization" is specifically tailored to solve a problem created by the nature of the problem to be solved, as well as the claim's own requirement that it receive multiple streams of high speed, high bandwidth raw data. Equating the "concurrent visualization" features of the asserted claims necessary to characterize the "living" electric power grid with the activity logs generated by the system claimed in *Ultramercial* is improper. And the district court's dismissal of multiple claim elements as being directed to routine post-solution activity is inappropriate and erroneous.

3. The District Court Failed to Analyze the Claims as an Ordered Combination

While the district court recognized the need to analyze the claims "as an ordered combination," it offered little, if any, genuine consideration of this requirement. After the district court dissected claim 12 into the eight self-fashioned "conceptual elements," it never stepped back to review its "conceptual elements" or the actual claim as an ordered combination. A26–27 (citing *Ultramercial*, 772 F.3d at 715). The district court's conclusion that the limitations "considered both individually and as an ordered combination fail to supply the necessary 'inventive concept' to transform the nature of the claims" falls short. A28; *see also*, *Alice*, 134 S. Ct. at 2355 ("To answer that question, we consider the elements of each claim both individually and as an ordered combination.") (internal quotations and citations omitted).

Analyzing the claims as an ordered combination shows that the claims provide much more than a basic measurement-based monitoring system employing "routine and conventional" features as stated by the district court. As discussed above, the claims specifically describe what data is to be monitored, the origin of the data, how the data is transformed, to what form the data is to be transformed into, and how the data is rendered into a concurrent visualization, such that an operator can understand the dynamic state of wide areas of the power grid without suffering data overwhelm. The recited features of the asserted claims require a particular order, and build upon one another such that analyzing the features or steps individually fails to capture the import of each feature as a progression in the ordered combination. When taken as a whole, a concrete, substantial, inventive and tangible monitoring system for the power grid becomes apparent.

And to the extent the district court rested its analysis on *Ultramercial*, the asserted claims differ substantively from the claims at issue in that case. As this Court found, the "ordered combination of steps [in *Ultramercial*] recite[d] an abstraction—an idea, having no particular concrete or tangible form." 772 F.3d at 715. As explained in this Court's holding, the various recited steps in *Ultramercial* merely described showing an advertisement before delivering free content or a method of using advertising as currency, a long-practiced economic concept merely being applied to the Internet. *Id.* at 715-16. The analyzed claim did not

explain any concrete or tangible way to facilitate the method that would make it more than a mere abstraction implemented using a generic computer. The asserted claims of the instant case are not directed to a routine business practice and include the specific, tangible implementation lacking in *Ultramercial*.

4. There is No Support for the District Court's Finding that the Asserted Claims Do Not Affect a Particular Concrete Solution to a Problem

Evidencing the complexity of this machine—and the need for a system to visualize and achieve situational awareness of otherwise incomprehensible data—is the August 2003 blackout. The "unforeseen and catastrophic blackout" of 2003 occurred but six days after EPG filed its provisional application, affected approximately 50 million people, and caused between $4 to $10 ***billion*** in losses. A4869-70 ¶23. The cause of that blackout was much later found to be "a lack of situational awareness over a wide area of the electric power grid." *Id.* ¶24; *see also* A4959. The asserted claims tackle that challenge with a substantial and concrete identification of: (1) the speed and frequency of the raw data streams to capture, (2) the specific subset of enumerated metrics to derive, (3) the specific types of grid and non-grid data to use, and (4) the way to assemble the transformed metrics in a user interface that "enables a user to 'visualize' [that electrical] machine and achieve situational awareness through dynamic representations of actual conditions affecting the reliability and performance of the grid from otherwise humanly

incomprehensible data collected over multiple, geographically disbursed points. A4780:17-22.

The asserted claims therefore provide substantial and concrete real-time monitoring systems and methods for the electric power grid having numerous specific features that provide an operator with previously unattainable situational awareness of the actual real-time, dynamic status of the electric power grid. The patented systems contribute to the safety and security of the electric power grid. In reaching its decision that the asserted claims recite routine and obvious steps, the district court ignored EPG's evidence, ignored a proper construction of the claims, improperly injected an obviousness discussion into the Section 101 analysis, and disregarded the ordered combination recited in the claims to solve the problem of data overwhelm created by the very data the claimed systems are limited to receive.

The asserted claims achieve the very charge set forth in *Alice*—to "integrate [those] building blocks into something more" thereby "'transform[ing]' them into a patent-eligible invention." *Alice*, 134 S. Ct. at 2355 (quoting *Mayo*, 132 S. Ct. at 1294). The asserted claims "pose no comparable risk of pre-emption" and thus "remain eligible for the monopoly granted under our patent laws." *Id*.

Based on the foregoing, the district court erred in its analysis of step two of the Mayo/Alice framework.

CONCLUSION

The district court's judgment should be reversed.

Dated: October 14, 2015

Respectfully submitted,

By */s/ Art Hasan*

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ADDENDUM

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UNITED STATES DISTRICT COURT

CENTRAL DISTRICT OF CALIFORNIA

Electric Power Group, LLC, Plaintiff, v. Alstom, S.A.; et al. Defendants.	)	Case No. CV 12-6365 JGB (RZx) JUDGMENT

TO ALL PARTIES AND THEIR ATTORNEYS OF RECORD:

Pursuant to the Order filed herewith, Defendants' Motion for Summary Judgment is hereby GRANTED.

Therefore, IT IS ORDERED AND ADJUDGED that Plaintiff's Complaint is DISMISSED WITH PREJUDICE. The Court orders that such judgment be entered.

The parties shall bear their own attorney fees.

Dated: May 21, 2015

Jesus G. Bernal
United States District Judge

UNITED STATES DISTRICT COURT
CENTRAL DISTRICT OF CALIFORNIA
CIVIL MINUTES—GENERAL

Case No.	**CV 12-06365-JGB (RZx)**	Date	May 21, 2015
Title	***Electric Power Group, LLC v. Alstom, S.A., et al.***		

Present: The Honorable	JESUS G. BERNAL, UNITED STATES DISTRICT JUDGE

MAYNOR GALVEZ	Not Reported
Deputy Clerk	Court Reporter
Attorney(s) Present for Plaintiff(s):	Attorney(s) Present for Defendant(s):
None Present	None Present

Proceedings: **Order GRANTING Defendants' Motion for Summary Judgment of Invalidity under 35 U.S.C. § 101 (Doc. No. 187);**
DENYING AS MOOT Plaintiff's Motion for Partial Summary Judgment of Direct Infringement (Doc. No. 191);
DENYING AS MOOT Defendants' Motion for Claim Construction (Doc. No. 186); and
DENYING AS MOOT Plaintiff's and Defendants' Motions in Limine (Doc. Nos. 185, 188, 189, 194, 202) (IN CHAMBERS)

Before the Court is Defendants Alstom, S.A.; Alstom Grid, Inc.; Psymetrix Ltd.; and Alstom Limited's motion for summary judgment of invalidity under 35 U.S.C. § 101. For the reasons below, the motion is GRANTED.

Before the Court are also Plaintiff Electric Power Group, LLC's motion for summary judgment of direct infringement and Defendants' motion for claim construction, as well as motions in limine filed by both parties. Because the Court's ruling on Defendants' motion for summary judgment is case-dispositive, the remaining motions are DENIED AS MOOT.

I. BACKGROUND

A. Procedural Background

Plaintiff Electric Power Group, LLC ("EPG" or "Plaintiff") alleges that Defendants Alstom, S.A.; Alstom Grid, Inc.; Psymetrix Ltd.; and Alstom Limited (collectively "Defendants") infringe three of its patents. Asserted in this action are claims 4, 7, 9, 12, 19, and 24 of U.S.

Patent No. 7,233,843; claims 1, 5, 18, 21, 38, 49, and 53 of U.S. Patent No. 8,060,259; and claims 9, 12, and 17 of U.S. Patent No. 8,401,710.[1]

B. Technological Background

The patents asserted in this action all come from continuations of the same patent application, and so share a specification. The invention disclosed by these patents relates to the management of electric power grids. When electric power is being generated, transmitted, and distributed, the demand placed on various parts of the system needs to be monitored and managed to prevent system failures, for instance, because of overload of a particular part of the system. Because power systems are enormous and complex, the task of managing them is daunting:

> Due to the enormous task at hand, there are a number of organizations responsible for overseeing these power generation, transmission and distribution activities. For example, there are over 3,000 utilities, thousands of generators, 22 Reliability Coordinators, and 153 Control Areas (CAs) in the United States for monitoring and control of generation, transmission and distribution of electricity. While all these different entities at various different levels are involved in generation, transmission and distribution of electricity as well as monitoring and control in a power grid, there is no single integrated system that can be used to monitor and manage the electric power grid in real-time across all of the different elements of the power system. For example, there is no information management system for the power grid, which is integrated across multiple business systems, companies and Control Areas to manage the security, timeliness, accuracy or accessibility of information for grid operations, reliability, market operations and system security.

’843 Patent at 1:63-2:14.

The patents-in-suit attempt to solve this problem by disclosing an integrated system for allowing real-time monitoring of metrics associated with the generation, transmission, and distribution of electric power across different elements of the power system, including those operated by different entities.

II. LEGAL STANDARD

A. Motion for Summary Judgment

Pursuant to Rule 56 of the Federal Rules of Civil Procedure, a “court shall grant summary judgment if the movant shows that there is no genuine issue as to any material fact and that the movant is entitled to judgment as a matter of law.” Fed. R. Civ. P. 56(a).

The Supreme Court’s 1986 trilogy of Celotex v. Catrett, 477 U.S. 317; Anderson v. Liberty Lobby, Inc., 477 U.S. 242; and Matsushita Electric Industrial Co. v. Zenith Radio Corp., 475 U.S. 574, requires that a party seeking summary judgment show the absence of a genuine issue

[1] The asserted claims are reproduced in Appendix A.

of material fact. Once the moving party has done so, the nonmoving party must "go beyond the pleadings and by [its] own affidavits, or by the depositions, answers to interrogatories, and admissions on file, designate specific facts showing that there is a genuine issue for trial." See Celotex, 477 U.S. at 324. "When the moving party has carried its burden under Rule 56(c), its opponent must do more than simply show that there is some metaphysical doubt as to the material facts." Matsushita, 475 U.S. at 586. "If the [opposing party's] evidence is merely colorable, or is not significantly probative, summary judgment may be granted." Liberty Lobby, 477 U.S. at 249-50. "[I]nferences to be drawn from the underlying facts," however, "must be viewed in the light most favorable to the party opposing the motion." See Matsushita, 475 U.S. at 587.

B. Patent-Eligible Subject Matter

Section 101 of the Patent Act defines the classes of patentable subject matter: "Whoever invents or discovers any new and useful process, machine, manufacture, or composition of matter, or any new and useful improvement thereof, may obtain a patent therefor, subject to the conditions and requirements of this title." 35 U.S.C. § 101.

Despite the apparent breadth of this language, § 101 has long contained "an important implicit exception: Laws of nature, natural phenomena, and abstract ideas are not patentable." Ass'n for Molecular Pathology v. Myriad Genetics, 133 S. Ct. 2107, 2116 (2013) (quoting Mayo Collaborative Services v. Prometheus Laboratories, 132 S. Ct. 1289, 1293 (2012)). The Supreme Court recently reaffirmed this principle in Alice Corp. v. CLS Bank Int'l, 134 S. Ct. 2347 (2014). The "concern that drives this exclusionary principle [is] one of pre-emption. . . . Monopolization of [laws of nature, natural phenomena, and abstract ideas] through the grant of a patent might tend to impede innovation more than it would tend to promote it, thereby thwarting the primary object of the patent laws." Id. at 2354.

However, the Supreme Court has repeatedly stressed the need to "tread carefully in construing this exclusionary principle lest it swallow all of patent law. At some level, all inventions embody, use, reflect, rest upon, or apply laws of nature, natural phenomena, or abstract ideas. Thus, an invention is not rendered ineligible for patent simply because it involves an abstract concept." Id. (internal citations omitted).

The Supreme Court has set forth a "framework for distinguishing patents that claim . . . abstract ideas from those that claim patent-eligible applications of those concepts. First, we determine whether the claims at issue are directed to one of those patent-ineligible concepts. If so, we then ask, 'what else is there in the claims before us?' . . . to determine whether the additional elements transform the nature of the claim into a patent-eligible application." Id. at 2355 (internal citations omitted). Step two of the analysis is a "search for an 'inventive concept'—i.e., an element or combination of elements that is sufficient to ensure that the patent in practice amounts to significantly more than a patent upon the ineligible concept itself." Id. (internal citations omitted).

Because patents are presumed valid, see 35 U.S.C. § 282, an alleged infringer asserting an invalidity defense bears the burden of proving invalidity by clear and convincing evidence. Microsoft Corp. v. i4i L.P., 131 S. Ct. 2238, 2242 (2011).

III. DISCUSSION

To determine patent eligibility, the Court "must first determine whether the claims at issue are directed to a patent-ineligible concept." Alice Corp. Pty. v. CLS Bank Int'l, 134 S. Ct. 2347, 2355 (2014). The Court concludes that the asserted claims from all three patents are drawn to the abstract idea of monitoring and analyzing data from multiple sources simultaneously.

Although each asserted claim articulates the invention slightly differently, claim 12 of the '710 patent exemplifies the general concept claimed by the patents. This claim recites:

> 12. A method of detecting events on an interconnected electric power grid in real time over a wide area and automatically analyzing the events on the interconnected electric power grid, the method comprising:
>
> receiving a plurality of data streams, each of the data streams comprising sub-second, time stamped synchronized phasor measurements wherein the measurements in each stream are collected in real time at geographically distinct points over the wide area of the interconnected electric power grid, the wide area comprising at least two elements from among control areas, transmission companies, utilities, regional reliability coordinators, and reliability jurisdictions;
>
> receiving data from other power system data sources, the other power system data sources comprising at least one of transmission maps, power plant locations, EMS/SCADA systems;
>
> receiving data from a plurality of non-grid data sources;
>
> detecting and analyzing events in real-time from the plurality of data streams from the wide area based on at least one of limits, sensitivities and rates of change for one or more measurements from the data streams and dynamic stability metrics derived from analysis of the measurements from the data streams including at least one of frequency instability, voltages, power flows, phase angles, damping, and oscillation modes, derived from the phasor measurements and the other power system data sources in which the metrics are indicative of events, grid stress, and/or grid instability, over the wide area;
>
> displaying the event analysis results and diagnoses of events and associated ones of the metrics from different categories of data and the derived metrics in visuals, tables, charts, or combinations thereof, the data comprising at least one of monitoring data, tracking data, historical data, prediction data, and summary data;
>
> displaying concurrent visualization of measurements from the data streams and the dynamic stability metrics directed to the wide area of the interconnected electric power grid;
>
> accumulating and updating the measurements from the data streams and the dynamic stability metrics, grid data, and non-grid data in real time as to wide area and local area portions of the interconnected electric power grid; and
>
> deriving a composite indicator of reliability that is an indicator of power grid vulnerability and is derived from a combination of one or more real time measurements or computations of measurements from the data streams and

> the dynamic stability metrics covering the wide area as well as non-power grid data received from the non-grid data source.

The "concept embodied by the majority of the limitations," Ultramercial, Inc. v. Hulu, LLC, 772 F.3d 709, 715 (Fed. Cir. 2014), reduces to the following conceptual elements:

1. Receiving data from different parts of an electric power grid
2. Receiving data from other power system data sources
3. Receiving data from non-grid data sources
4. Detecting and analyzing events in real-time from the data sources
5. Displaying the event analysis results
6. Displaying a visualization of the data received
7. Accumulating and updating the data from the multiple data sources
8. Deriving a composite indicator of reliability from the multiple data sources

"Although certain additional limitations, such as [enumerating the metrics to be collected and analyzed from the data sources], add a degree of particularity, the concept embodied by the majority of the limitations describes only the abstract idea of" collecting, analyzing, and displaying data from multiple sources simultaneously. Ultramercial, 772 F.3d at 715. Limitations 1-3 above merely recite the abstract idea of collecting data from various different data sources, while limitations 4-8 recite the abstract idea of analyzing and displaying that data.

EPG asserts two primary arguments to avoid this conclusion. First, EPG faults Defendants for failing to provide "evidence" that the asserted claims are directed to an abstract concept. ("Opp'n," Doc. No. 211 at 6.) This argument is unpersuasive. Although a determination of patent eligibility "may contain underlying factual issues," it is ultimately a "legal conclusion." Accenture Global Servs., GmbH v. Guidewire Software, Inc., 728 F.3d 1336, 1341 (Fed. Cir. 2013). While Defendants are required to prove any underlying factual issues by clear and convincing evidence, i4i, 131 S. Ct. at 2242, EPG fails to point to any particular factual issue on which Defendants' argument depends. Indeed, of the evidence submitted by EPG in opposition to Defendants' motion for summary judgment, all evidence properly characterized as factual is consistent with Defendants' position. The only evidence that contradicts Defendants' position is evidence that is improperly directed to legal conclusions rather than factual disputes. (See, e.g., Winter Decl., Doc. No. 211-2 ¶ 53 ("Monitoring the electric power grid is not an abstract idea.").)

Second, EPG argues that the claimed invention "constitutes a substantial technological advance" and that "[t]he claimed inventions are novel over the prior art." (Opp'n at 7.) This may be true, but it is irrelevant to whether the patent attempts to claim an abstract idea. "A self-driving car . . . might be novel and—its implementation, at least—non-obvious. But that doesn't make the concept of a self-driving car any less abstract. The first inventor to successfully create a self-driving car might be able to patent his specific implementation of the idea with appropriately narrow claim language, limited to the inventor's particular implementation. But the inventor could not patent self-driving cars in the abstract, no matter how novel . . . his particular self-driving car might be." Hewlett Packard Co. v. ServiceNow, Inc., No. 14-CV-00570, 2015 WL 1133244, at *10 (N.D. Cal. Mar. 10, 2015).

Having determined that the claim is drawn to the abstract idea of monitoring and analyzing data from disparate sources, the Court now turns to the second step of the Alice analysis. This step requires the Court "to determine whether the claims do significantly more than simply

describe that abstract method." Ultramercial, 772 F.3d at 715. While the claim does include additional limitations, the Court concludes that the limitations, considered both individually and as an ordered combination, fail to supply the necessary "inventive concept" to transform the nature of the claims from a patent on the ineligible concept into a patent-eligible application of the concept. See Alice, 134 S. Ct. at 2355.

In considering the additional elements of the claim, the Court recognizes that "limiting an abstract idea to one field of use" does not make an abstract idea patentable. Bilski v. Kappos, 561 U.S. 593, 612 (2010). Similarly, "[a]dding routine additional steps . . . does not transform an otherwise abstract idea into patent-eligible subject matter." Ultramercial, 772 F.3d at 716. Nor can the inclusion of "conventional or obvious" elements or insignificant post- or pre-solution activity save an otherwise invalid claim from invalidation. Id. (citing Mayo Collaborative Servs. v. Prometheus Labs., Inc., 132 S. Ct. 1289, 1298 (2012)); Parker v. Flook, 437 U.S. 584, 590 (1978). Finally, while the machine-or-transformation test is a "useful and important clue" for determining patent eligibility, "satisfying the machine-or-transformation test, by itself, is not sufficient to render a claim patent-eligible." DDR Holdings, LLC v. Hotels.com, L.P., 773 F.3d 1245, 1255-56 (Fed. Cir. 2014) (citing Bilski v. Kappos, 561 U.S. 593, 604 (2010)).

The most significant additional limitations in the asserted claim are those that limit the claim to monitoring and analyzing data in the context of electric power grids. But the fact that the claim is limited to power grid management does not change the nature of the claims from abstract to concrete. "Flook establishes that limiting an abstract idea to one field of use . . . did not make the concept patentable." Bilski, 561 U.S. at 612 (citing Flook, 437 U.S. 584).

Similarly, while enumerating the particular metrics to be monitored does limit the claim's scope, it does not transform the nature of the claims into a patent-eligible application of the abstract idea. The enumerated metrics are simply routine, conventional metrics, so limiting the claims to monitoring and analyzing those metrics does not supply any sort of "inventive concept." Alice, 134 S. Ct. at 2355. It merely limits the abstract idea to one field of use, which is insufficient under Flook.

Indeed, even if some of the enumerated metrics were novel or non-routine, it would not transform the nature of the claims. See Ultramercial, 772 F.3d at 715 ("We do not agree . . . that the addition of merely novel or non-routine components to the claimed idea necessarily turns an abstraction into something concrete."). Like the claims at issue in Ultramercial, the claims asserted in this action "simply instruct the practitioner to implement the abstract idea with routine, conventional activity. None of these . . . individual steps, viewed 'both individually and "as an ordered combination"' transform the nature of the claim into patent eligible subject matter." Ultramercial, 772 F.3d at 715 (citing Alice, 134 S. Ct. at 2355).

Conceptual limitations 4 through 8 above also fail to transform the nature of the claims because they merely recite routine additional steps and insignificant post-solution activity. See Ultramercial, 772 F.3d at 716. Limitation 4—detecting and analyzing events in real-time from the data sources—is purely conventional post-solution activity. Even if the specification disclosed some novel way of performing the analysis, the claim limitation is described in purely generic, abstract terms, which would cover even conventional forms of analysis and event detection. It may be that reciting a particular form of detection and analysis to be performed would be sufficient to render the claim a patent-eligible application of the abstract concept, but generically reciting that the data is to be analyzed and events are to be detected is insufficient to

change the nature of the claim from an "abstraction into something concrete." See Ultramercial, 772 F.3d at 715.

Limitation 5—displaying the event analysis results—is similarly insufficient to change the nature of the claims. Displaying the results of an analysis is a conventional activity and nothing in this limitation supplies an additional inventive concept. Limitation 5 is merely a recitation of insignificant post-solution activity. See id. at 716.

Limitation 6—displaying a visualization of the data received—is merely a recitation of insignificant post-solution activity, which can be accomplished using conventional methods. Plaintiff argues that this limitation "cover[s] advanced visualizations including dynamic graphic and geographic displays." (Opp'n at 9 n.5.) But the claim language isn't limited to "advanced visualizations." Even if the specification discloses some novel form of data visualization, nothing in the claim language limits the claims to such novel visualizations. The inventors could have chosen to claim only particular novel data visualization techniques enabled by the specification, and such a claim limitation might well be sufficient to supply an inventive concept. But because the claim limitation merely recites generic visualization of the data, it does nothing more than add routine and conventional post-solution activity.

Limitation 7—accumulating and updating the data from the multiple data sources—also adds only insignificant post-solution activity that can be performed using conventional methods. Plaintiff does not contend—nor could it plausibly contend—that accumulating and updating data from various sources requires anything more than conventional and routine programming procedures. Thus, this limitation fails to provide an inventive concept.

Finally, limitation 8—deriving a composite indicator of reliability from the multiple data sources—might be sufficient to supply an inventive concept if it claimed a particular, novel method of deriving a composite indicator of reliability from the multiple data sources. However, the claim is not so limited. Instead, it generically recites deriving a composite indicator without requiring any particular novel method of deriving the indicator. Accordingly, this claim limitation would be satisfied by any composite indicator of reliability, even one derived using conventional or routine methods. Accordingly, this limitation merely recites insignificant post-solution activity and fails to provide an inventive concept sufficient to alter the nature of the claim.

Because the claim recites an abstract idea, merely limiting that idea to a particular field of use and adding insignificant or routine post-solution activity are insufficient to transform the claim from an attempt to patent the abstract idea into a patent-eligible application of the idea. Because the claim fails both steps of the Supreme Court's Alice analysis, the claim is invalid under 35 U.S.C. § 101.

The Court reaches this conclusion fully cognizant of the need to "tread carefully in construing this exclusionary principle lest it swallow all of patent law." Alice, 134 S. Ct. at 2354. The Court assumes for purposes of this motion that the development of software capable of simultaneously monitoring and analyzing data from multiple power grid operators represents a novel development in the art. Accordingly, there may well be a patentable invention couched somewhere in the specification of the patents-in-suit. But for purposes of patent-eligibility under 35 U.S.C. § 101, it is the claims that matter. Rather than specifically claiming an invention that enables computers to perform simultaneous monitoring and analysis of multiple data sources

across a power grid, the patents-in-suit claim the abstract idea of performing the simultaneous monitoring.

In other words, while the specification may indeed disclose a patentable specific solution to a problem—i.e. some specific way of enabling a computer to monitor data from multiple sources across an electric power grid—the asserted claims purport to monopolize every potential solution to the problem. This raises exactly the kind of preemption concerns that drive the exclusionary principle. Granting a monopoly on a particular method for simultaneously monitoring data from multiple power grid operators would incentivize further innovation in the form of alternative methods for achieving the same result. In contrast, granting a monopoly on the result itself—the successful monitoring of data from multiple power grid operators—inhibits innovation by prohibiting other inventors from developing their own solutions to the problem without first licensing the abstract idea.

In sum, there is a critical difference between patenting a particular concrete solution to a problem and attempting to patent the abstract idea of a solution to the problem in general. Cf. DDR Holdings, LLC v. Hotels.com, L.P., 773 F.3d 1245, 1259 (Fed. Cir. 2014) (finding patent eligibility because "the claims at issue do not attempt to preempt every application of the idea of increasing sales by making two web pages look the same . . . . Rather, they recite a specific way to automate the creation of a composite web page . . ."). Here, the problem is the need to monitor and analyze data from multiple distinct parts of a power grid. It may very well be valid to patent a particular implementation for solving this problem. But that does not mean the first inventor to develop such an implementation can prohibit all others from developing their own solutions by patenting the abstract notion of solving the problem. That is exactly what EPG's claims attempt to do, and as such, they are directed to the patent-ineligible abstract idea of solving the problem, rather than to a patent-eligible solution to the problem.

The Court has separately considered all other claims asserted in this action and has determined that rearticulating the same analysis for each one is unnecessary, as they all suffer the same basic infirmity: rather than attempting to claim a concrete solution of how to monitor and analyze data from multiple different power grid sources, they all attempt to claim the abstract idea of monitoring and analyzing data from multiple different power grid sources. In so doing, they are monopolizing the abstract idea of solving the problem rather than merely monopolizing a single concrete solution to the problem. The additional limitations contained in the various claims merely recite "routine or obvious" elements, or add insignificant pre- or post-solution activity, and thus fail to provide an inventive concept sufficient to transform the claims into concrete applications of the abstract idea. Because of this, the asserted claims are directed to patent-ineligible subject matter and are invalid under 35 U.S.C. § 101. See Content Extraction & Transmission LLC v. Wells Fargo Bank, Nat. Ass'n, 776 F.3d 1343, 1348 (Fed. Cir. 2014) (approving the use of representative claims where "all the claims are substantially similar and linked to the same abstract idea").

IV. CONCLUSION

Because the asserted claims are directed to patent-ineligible subject matter, Defendants are entitled to judgment as a matter of law. This renders any remaining factual disputes immaterial. Because there are no genuine disputes of material fact, summary judgment is appropriate. Accordingly, Defendants' motion for summary judgment is GRANTED.

Because the Court's ruling on Defendants' motion for summary judgment is case-dispositive, the remaining motions are DENIED AS MOOT.

IT IS SO ORDERED.

Appendix A

U.S. Patent No. 7,233,843

Claim 1 (not asserted)

A real-time performance monitoring system for monitoring an electric power grid, comprising:

a monitor computer for monitoring at least one of reliability metrics, power grid operations metrics, generation metrics, transmission metrics, suppliers metrics, grid infrastructure security metrics or markets metrics over a plurality of control areas of the electric power grid operated on a plurality of different platforms by a plurality of different business systems or companies;

a database for storing the metrics being monitored by the monitor computer; and

at least one display computer in at least one of said plurality of control areas of the electric power grid, the at least one display computer having a monitor for displaying a visualization of the metrics being monitored by the monitor computer,

said at least one display computer in one of said plurality of control areas being adapted to enable an operator located in and responsible for monitoring the one of said plurality of control areas to monitor one or more of said plurality of control areas that are different from the control area in which the operator is located.

Claim 4

The real-time performance monitoring system of claim 1,

wherein the monitor computer includes an application for monitoring the grid infrastructure security metrics, and wherein said application performs real-time monitoring of at least one of system vulnerability including phasor measurements and changes thereof or exposure in terms of at least one of population or cities.

Claim 6 (not asserted)

The real-time performance monitoring system of claim 1,

wherein at least one of the monitor computer or said at least one display computer performs at least one of historical tracking, prediction or actions related to the metrics being monitored, wherein the actions related to the metrics being monitored include actions related to one or more violations of one or more predefined thresholds, wherein

the one or more violations are communicated in real time through alarms or other communication systems.

Claim 7

The real-time performance monitoring system of claim 6,
wherein the monitor displays a visualization of data representing said at least one of historical tracking, prediction or actions related to the metrics being monitored.

Claim 9

The real-time performance monitoring system of claim 1,
wherein the monitor concurrently displays at least one dynamic geographic display and a plurality of data or text panels for at least one of monitoring, tracking, prediction, actions or mitigations.

Claim 12

The real-time performance monitoring system of claim 1,
wherein an operator of at least one of the monitor computer or said at least one display computer can define an application to monitor metrics, which are related to the electric power grid at the local level, control area level, or regional level covering a wide area, which the operator desires to monitor.

Claim 19

The real-time performance monitoring system of claim 1,
wherein the monitor computer monitors proximity to potential system faults, and said at least one display computer graphically represents the proximity to potential system faults on the monitor.

Claim 24

The real-time performance monitoring system of claim 1:
wherein the reliability metrics, power grid operations metrics, generation metrics, transmission metrics, suppliers metrics, grid infrastructure security metrics or markets metrics for the electric power grid are monitored across a wide area covering multiple control areas and utilities;
wherein each of the plurality of grid portions includes a network of high voltage transmission lines and generators interconnected to the

network that is spread out over the multiple control areas across the wide area;

wherein the plurality of grid portions are subject to power blackouts that spread or cascade over the wide area; and

wherein the operator is a reliability coordinator having responsibility to:

monitor the power grid metrics over the wide area for reliability management; and

prevent power blackouts that spread or cascade over the wide area.

U.S. Patent No. 8,060,259

Claim 1

A wide-area real-time performance monitoring system for monitoring and assessing dynamic stability of an electric power grid, the system comprising:

a monitor computer including an interface for receiving a plurality of data streams, each data stream comprising sub-second, time stamped synchronized phasor measurements wherein the measurements in each stream are collected at geographically distinct points over a wide area of the grid;

wherein the monitor computer monitors metrics including at least one of reliability metrics, power grid operations metrics, generation metrics, transmission metrics, suppliers metrics, grid infrastructure security metrics or market metrics over a wide area of the electric power grid, wherein the wide area comprises at least two distinct entities selected from the group consisting of transmission companies, utilities, and regional reliability coordinators;

wherein the monitor computer derives in real-time from the plurality of data streams from the at least two distinct entities selected from the group consisting of transmission companies, utilities, and regional reliability coordinators, one or more dynamic stability metrics including phase angles, damping, oscillation modes, and sensitivities for dynamics monitoring using phasor measurements in which the stability metrics are indicative of grid stress and/or instability, over the wide area; and

wherein the monitor computer is configured to supply at least two different categories of data concern the metrics to a graphical user interface coupled to the monitor computer for concurrently displaying the at least two different categories of data concerning the metrics,

wherein the categories of data include monitoring data, tracking data, historical data, prediction data, and summary data,

wherein the graphical user interface provides concurrent visualization of a plurality of metrics directed to a wide geographic area of the grid covering at least two distinct entities selected from the group

consisting of transmission companies, utilities, and regional reliability coordinators, and

wherein the computer accumulates and updates wide area dynamic performance metrics in real time as to wide area and local area portions of the grid.

Claim 2 (not asserted)

The performance monitoring system of claim 1,

wherein the monitor computer analyzes the monitored metrics and the graphical user interface displays results of analyzing the metrics.

Claim 5

The performance monitoring system of claim 2,

wherein the monitor computer is configured to transfer the results of the analysis to another computer system for display, further analysis, or as an input for another calculation.

Claim 17 (not asserted)

A method of performing wide area real time monitoring and assessment of dynamic stability of an electric power grid comprising:

receiving a plurality of data streams, each data stream comprising sub-second, time stamped synchronized phasor measurements wherein the measurements in each stream are collected at geographically distinct points over a wide area of the grid comprising at least two distinct entities selected from the group consisting of transmission companies, utility companies, and regional reliability coordinators;

monitoring dynamic stability metrics including phase angles, damping, oscillation modes, and sensitivities over the wide area of the electric power grid;

deriving in real-time from the plurality of data streams one or more stability metrics for dynamics monitoring using phasor measurements which are indicative of grid stress and/or instability;

updating the monitored metrics in real time;

concurrently displaying in graphical form at least two different categories of data concerning the metrics, wherein the categories are selected from a group consisting of monitoring data, tracking data, historical data, prediction data, and summary data;

updating the displayed data in real time;

analyzing the displayed data;

providing summary information concerning real time performance of the electric power grid; and

storing the data in real time for replay and review to perform power grid system performance assessment, event diagnostics, root cause

analysis of events and situational assessment of dynamic stability of the electric power grid in real time.

Claim 18

The method of claim 17 further comprising
identifying monitored data of a portion of the electric power grid that crosses a threshold.

Claim 21

The method of claim 17, further comprising
drilling down or zooming in and viewing data across the metrics and across the geographically distinct points.

Claim 22 (not asserted)

A wide area real-time dynamics monitoring system for assessing dynamic stability of an electric power grid, the system comprising:
a monitor computer for receiving a plurality of data streams, each data stream comprising sub-second, time stamped synchronized phasor measurements wherein the measurements in each stream are collected at geographically distinct points over a wide area of the grid, the plurality of data streams being received by the monitor computer from third party utilities or transmission companies that provide the data, wherein the wide area comprises at least two distinct entities selected from the group consisting of transmission companies, utilities, and regional reliability coordinators,
wherein the monitor computer derives in real-time from the plurality of data streams from the at least two distinct entities one or more dynamic stability metrics including phase angles, damping, oscillation modes, and sensitivities for dynamics monitoring using phasor measurements in which the stability metrics are indicative of grid stress and instability, over the wide area, and
wherein the derived metrics include at least one of reactive reserve margin, power transfer angle, voltage/volt-ampere reactive (VAR), frequency response, sensitivities and/or combinations thereof;
a database to store the measurements and derived metrics; and
a display operatively coupled to the monitor computer and database for visualization of information relating to the plurality of the measurements and derived metrics relevant to the assessment of the

real-time dynamic stability of wide area and local area portions of the grid.

Claim 38

The wide area real-time dynamics monitoring system of claim 22,
wherein an operator of the monitor computer can define an application to monitor the derived metrics, which are related to the electric power grid at a local level, control area level, or regional level covering the wide area that the operator desires to monitor.

Claim 49

The wide area real-time dynamics monitoring system of claim 22,
wherein the monitor computer tracks, identifies and saves data on defined or abnormal operating conditions in a database, and the display provides visualization of the abnormal operating conditions.

Claim 53

The wide area real-time dynamics monitoring system of claim 22,
wherein the monitor computer is configured to store the data in real time for replay and review to perform power grid system performance assessment, event diagnostics, root cause analysis of events and situational assessment of dynamic stability of the electric power grid in real time.

U.S. Patent No. 8,401,710

Claim 9

A wide-area real-time performance monitoring system for collecting, storing and analyzing event data and analysis of events on an interconnected electric power grid in real time over a wide area and automatically analyzing the events on the interconnected electric power grid, the system comprising:
a monitor computer including an interface for receiving a plurality of data streams, each of data streams comprising sub-second, time stamped synchronized phasor measurements wherein the measurements in each stream are collected in real time at geographically distinct points over the wide area of the interconnected electric power grid, the wide area comprising at least two elements from among control areas, transmission companies,

utilities, regional reliability coordinators, and reliability jurisdictions;

a plurality of interfaces to other power system data sources, the other power system data sources comprising at least one of transmission maps, power plant locations, EMS/SCADA systems;

a plurality of interfaces to non-grid data sources;

a database configured to store the phasor measurements and a plurality of derived metrics; and

a display coupled to the monitor computer and the database for visualization of information relating to the plurality of the phasor measurements and the derived metrics relevant to assessing the real-time dynamic stability of wide area and local area portions of the interconnected electric power grid,

wherein the monitor computer is configured to monitor metrics, the metrics comprising at least one of reliability metrics, power grid operations metrics, generation metrics, transmission metrics, suppliers metrics, grid infrastructure security metrics, and market metrics over the wide area of the interconnected electric power grid,

wherein the monitor computer is configured to detect events in real-time from the plurality of data streams from the wide area,

wherein the monitor computer is configured to execute event detection logic, the event detection logic being configured to detect and analyze an event based on at least one of limits, sensitivities, and rates of change for one or more measurements from the data streams and dynamic stability metrics derived from analysis of the measurements from the data streams including at least one of frequency instability, voltages, power flows, phase angles, damping, and oscillation modes, derived from the phasor measurements and the other power system data sources in which the metrics are indicative of events, grid stress and/or grid instability, over the wide area, and

wherein the metrics associated with a detected event comprise include at least one of time of event, location of event, type of event, magnitude of event, and one or more key event related metrics such as frequency, delta frequency, voltage drop, reactive reserve margin, power transfer angle, voltage/volt-ampere reactive (VAR), frequency response, sensitivities and/or combinations thereof.

Claim 12

A method of detecting events on an interconnected electric power grid in real time over a wide area and automatically analyzing the events on the interconnected electric power grid, the method comprising:

receiving a plurality of data streams, each of the data streams comprising sub-second, time stamped synchronized phasor measurements wherein the measurements in each stream are collected in real time at geographically distinct points over the wide

area of the interconnected electric power grid, the wide area comprising at least two elements from among control areas, transmission companies, utilities, regional reliability coordinators, and reliability jurisdictions;

receiving data from other power system data sources, the other power system data sources comprising at least one of transmission maps, power plant locations, EMS/SCADA systems;

receiving data from a plurality of non-grid data sources;

detecting and analyzing events in real-time from the plurality of data streams from the wide area based on at least one of limits, sensitivities and rates of change for one or more measurements from the data streams and dynamic stability metrics derived from analysis of the measurements from the data streams including at least one of frequency instability, voltages, power flows, phase angles, damping, and oscillation modes, derived from the phasor measurements and the other power system data sources in which the metrics are indicative of events, grid stress, and/or grid instability, over the wide area;

displaying the event analysis results and diagnoses of events and associated ones of the metrics from different categories of data and the derived metrics in visuals, tables, charts, or combinations thereof, the data comprising at least one of monitoring data, tracking data, historical data, prediction data, and summary data;

displaying concurrent visualization of measurements from the data streams and the dynamic stability metrics directed to the wide area of the interconnected electric power grid;

accumulating and updating the measurements from the data streams and the dynamic stability metrics, grid data, and non-grid data in real time as to wide area and local area portions of the interconnected electric power grid; and

deriving a composite indicator of reliability that is an indicator of power grid vulnerability and is derived from a combination of one or more real time measurements or computations of measurements from the data streams and the dynamic stability metrics covering the wide area as well as non-power grid data received from the non-grid data source.

Claim 17

The method of claim 12, further comprising

enabling a user to drill down and visualize the metrics displayed on a graphical user interface at various geographical resolutions ranging from wide-area to local-area.

US008060259B2

(12) **United States Patent**
Budhraja et al.

(10) **Patent No.: US 8,060,259 B2**
(45) **Date of Patent: *Nov. 15, 2011**

(54) **WIDE-AREA, REAL-TIME MONITORING AND VISUALIZATION SYSTEM**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1094 days.

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See application file for complete search history.

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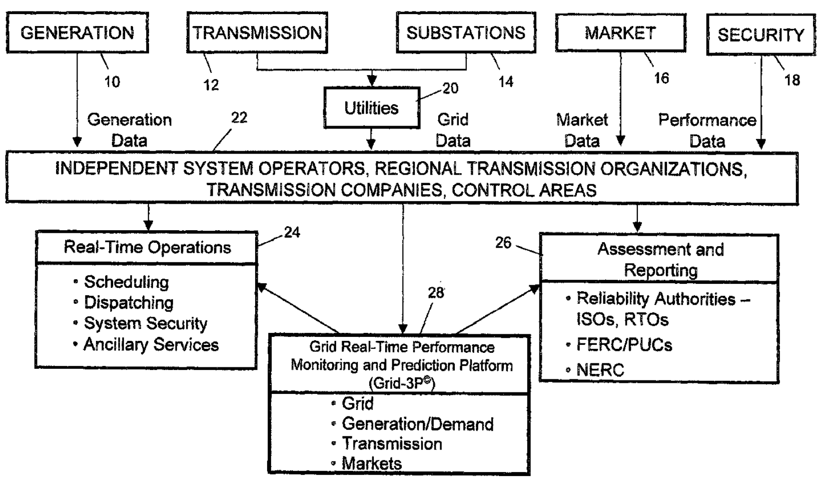
(57) **ABSTRACT**

A real-time performance monitoring system for monitoring an electric power grid. The electric power grid has a plurality of grid portions, each grid portion corresponding to one of a plurality of control areas. The real-time performance monitoring system includes a monitor computer for monitoring at least one of reliability metrics, generation metrics, transmission metrics, suppliers metrics, grid infrastructure security metrics, and markets metrics for the electric power grid. The data for metrics being monitored by the monitor computer are stored in a data base, and a visualization of the metrics is displayed on at least one display computer having a monitor. The at least one display computer in one said control area enables an operator to monitor the grid portion corresponding to a different said control area.

53 Claims, 41 Drawing Sheets



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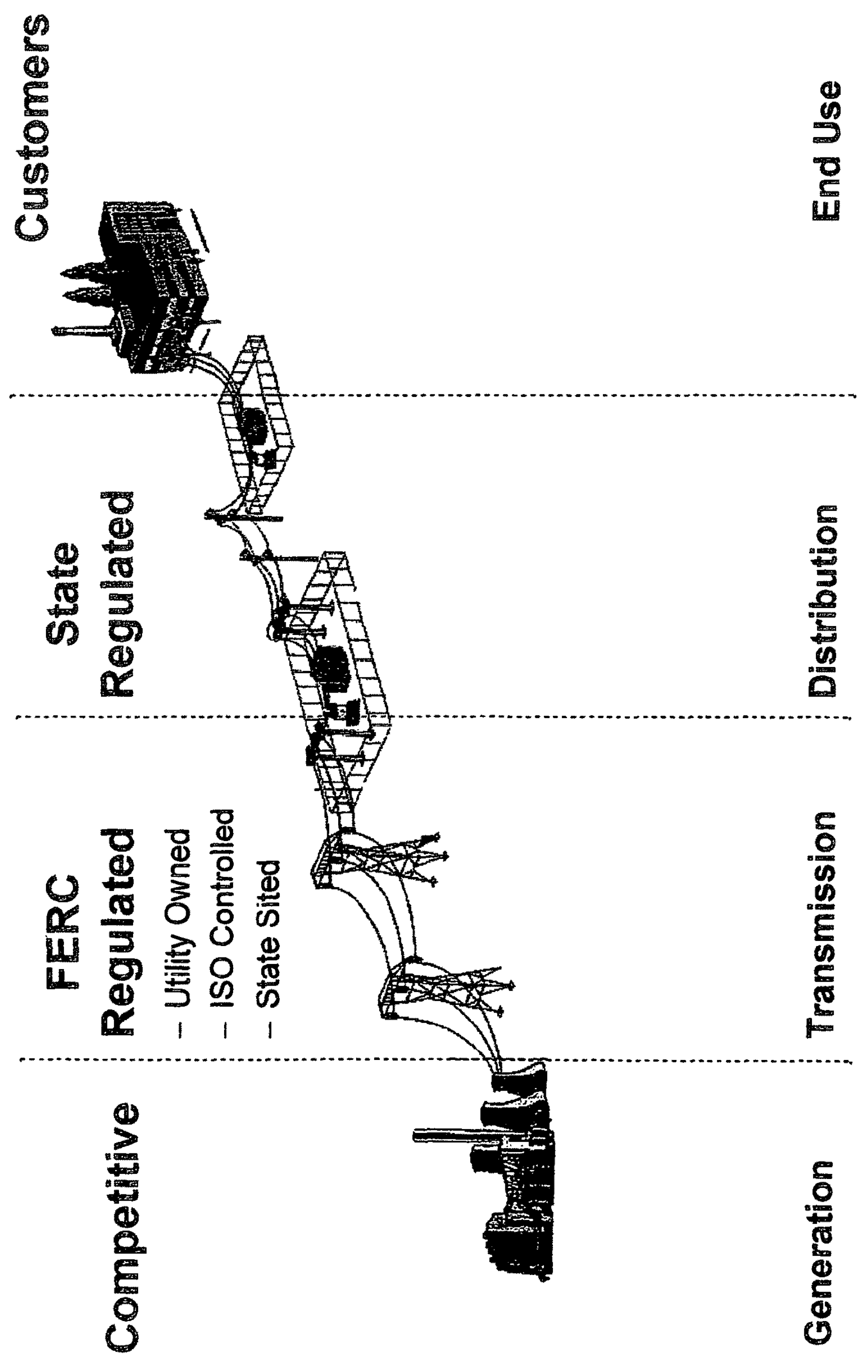


FIG. 1A
PRIOR ART

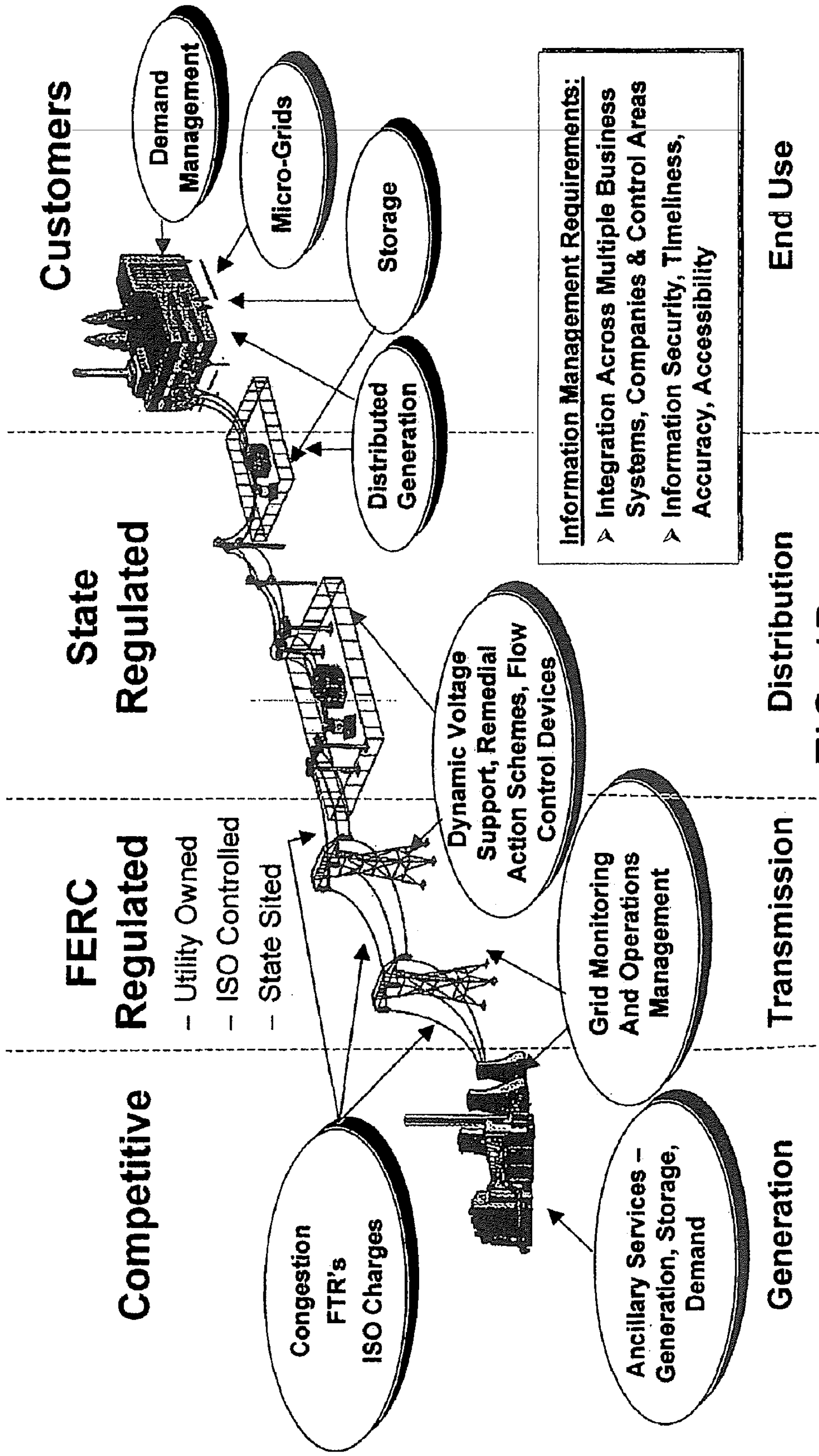

Competitive
FERC Regulated
– Utility Owned
– ISO Controlled
– State Sited
State Regulated
Customers
Congestion FTR's ISO Charges
Ancillary Services – Generation, Storage, Demand
Grid Monitoring And Operations Management
Dynamic Voltage Support, Remedial Action Schemes, Flow Control Devices
Distributed Generation
Storage
Micro-Grids
Demand Management
Information Management Requirements:
Integration Across Multiple Business Systems, Companies & Control Areas
Information Security, Timeliness, Accuracy, Accessibility
Generation
Transmission
Distribution
End Use

FIG. 1B

Performance Management Strategy

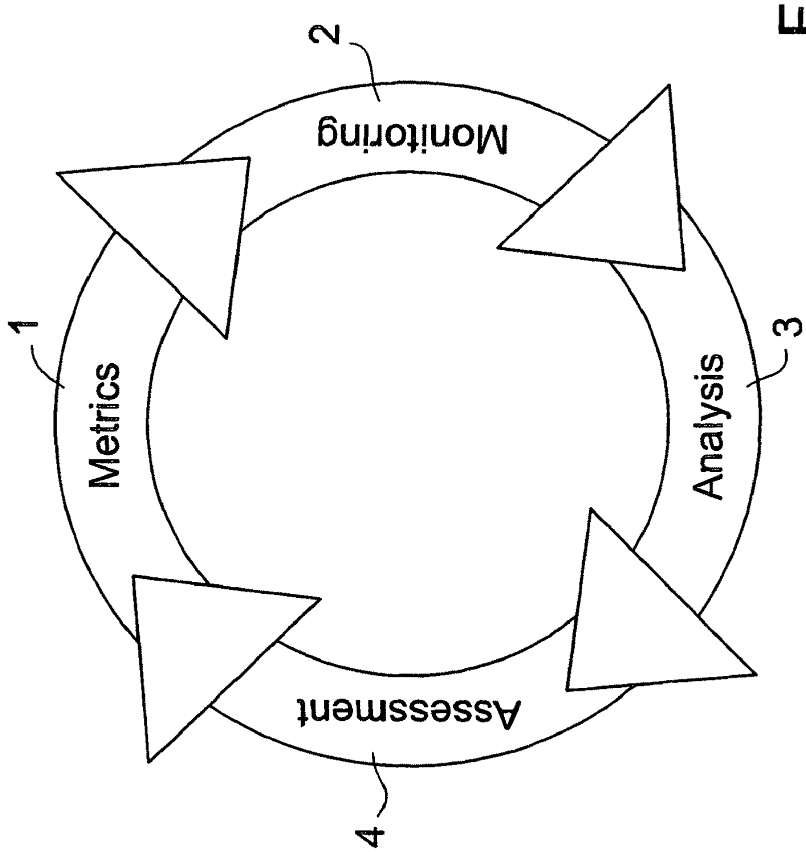


FIG. 2A

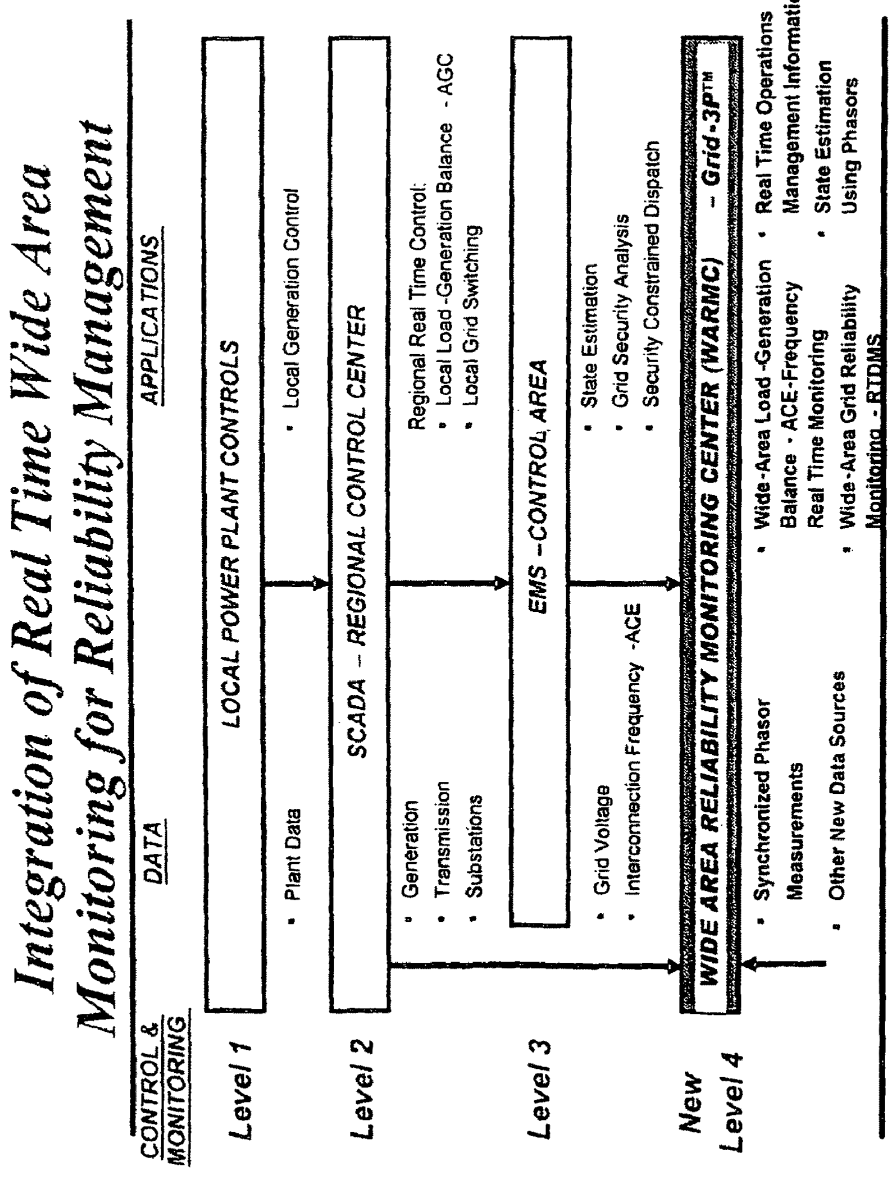

Integration of Real Time Wide Area Monitoring for Reliability Management
CONTROL & MONITORING
DATA
APPLICATIONS
Level 1
LOCAL POWER PLANT CONTROLS
Plant Data
Local Generation Control
Level 2
SCADA – REGIONAL CONTROL CENTER
Generation
Transmission
Substations
Regional Real Time Control:
Local Load -Generation Balance - AGC
Local Grid Switching
Level 3
EMS –CONTROL AREA
Grid Voltage
Interconnection Frequency -ACE
State Estimation
Grid Security Analysis
Security Constrained Dispatch
New Level 4
WIDE AREA RELIABILITY MONITORING CENTER (WARMC) – Grid-3P™
Synchronized Phasor Measurements
Other New Data Sources
Wide-Area Load -Generation Balance - ACE-Frequency Real Time Monitoring
Wide-Area Grid Reliability Monitoring - RTDMS
Real Time Operations Management Information
State Estimation Using Phasors

FIG. 2B

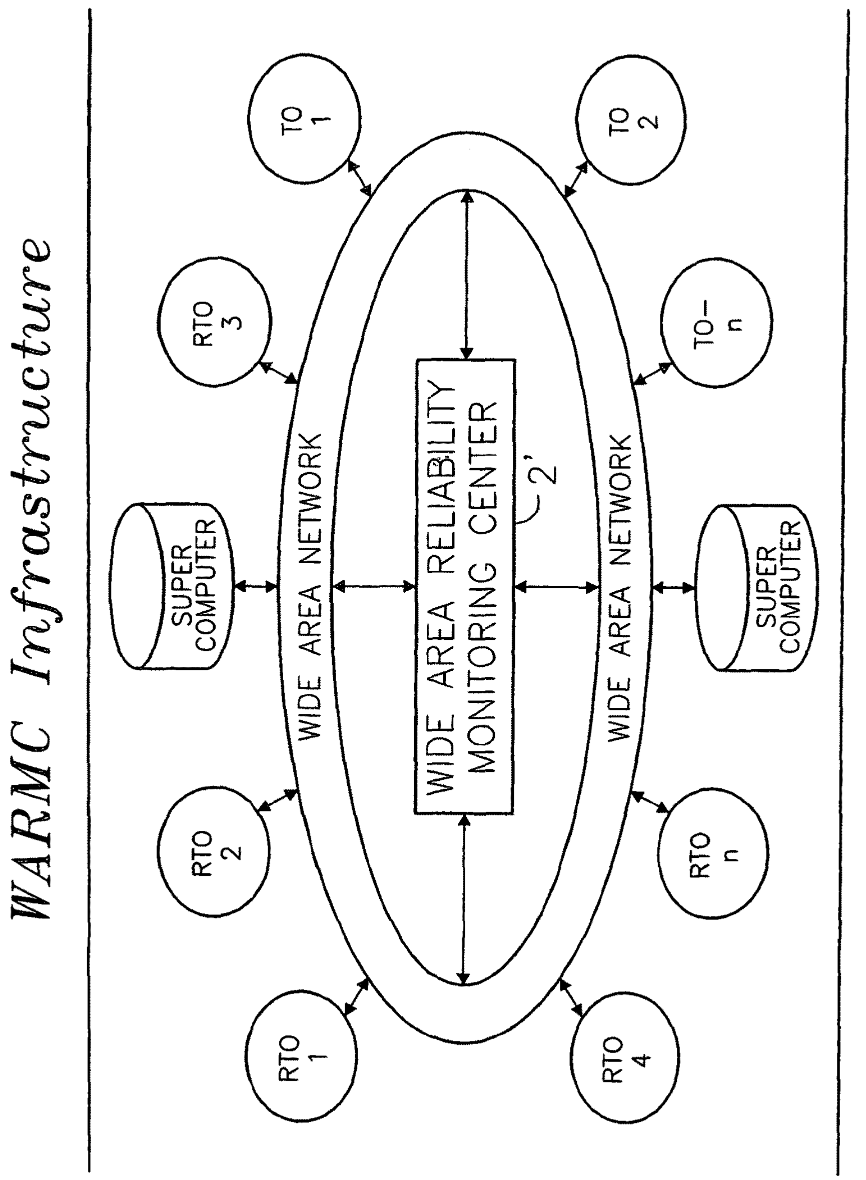
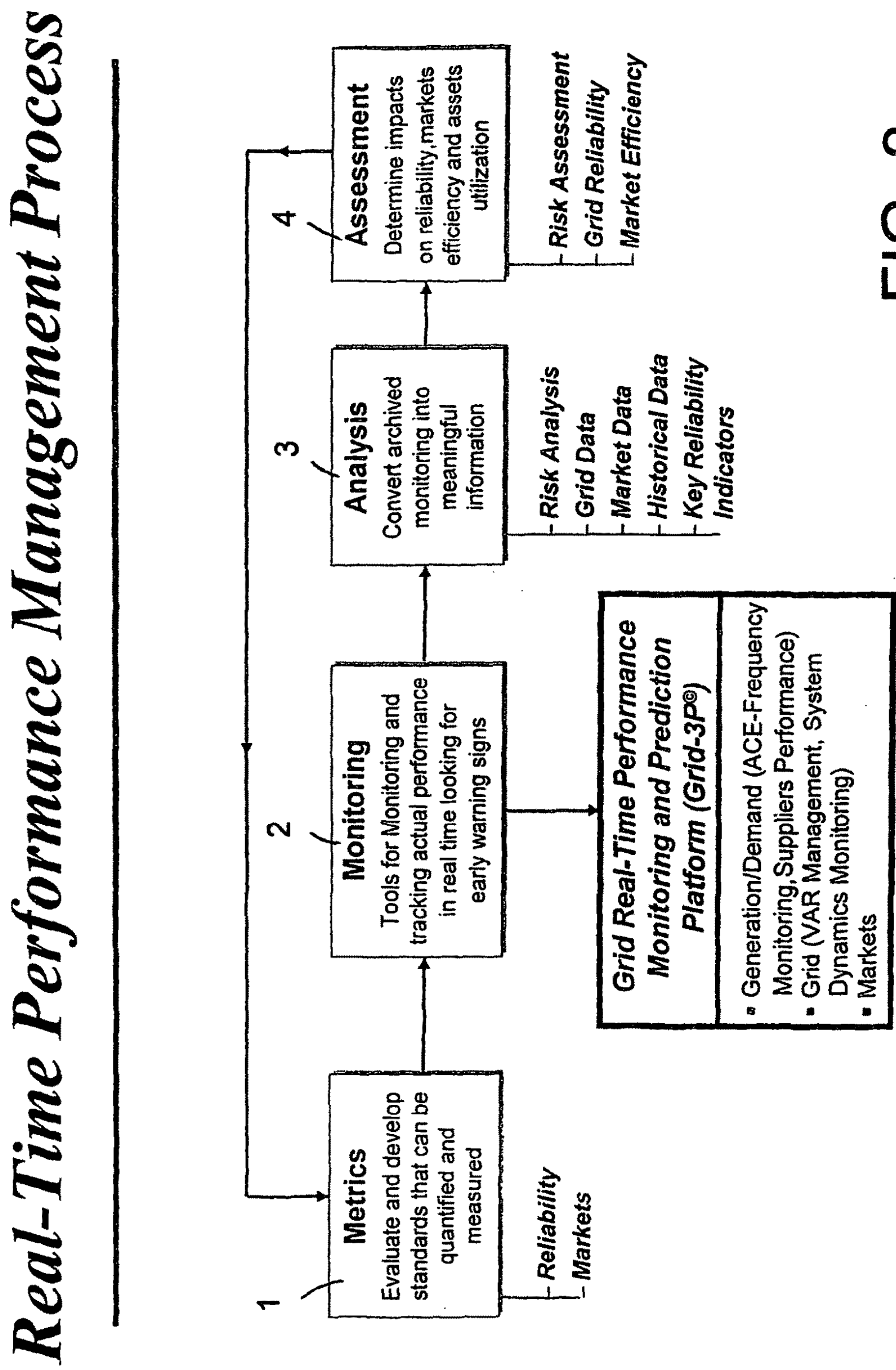

WARMC Infrastructure
TO 1
TO 2
RTO 3
TO- n
SUPER COMPUTER
WIDE AREA NETWORK
WIDE AREA RELIABILITY MONITORING CENTER
2'
WIDE AREA NETWORK
SUPER COMPUTER
RTO 2
RTO n
RTO 1
RTO 4

FIG. 2C



Real-Time Performance Management Process
1
Metrics
Evaluate and develop standards that can be quantified and measured
Reliability
Markets
2
Monitoring
Tools for Monitoring and tracking actual performance in real time looking for early warning signs
3
Analysis
Convert archived monitoring into meaningful information
Risk Analysis
Grid Data
Market Data
Historical Data
Key Reliability Indicators
4
Assessment
Determine impacts on reliability, markets efficiency and assets utilization
Risk Assessment
Grid Reliability
Market Efficiency
Grid Real-Time Performance Monitoring and Prediction Platform (Grid-3P©)
Generation/Demand (ACE-Frequency Monitoring, Suppliers Performance)
Grid (VAR Management, System Dynamics Monitoring)
Markets

FIG. 3

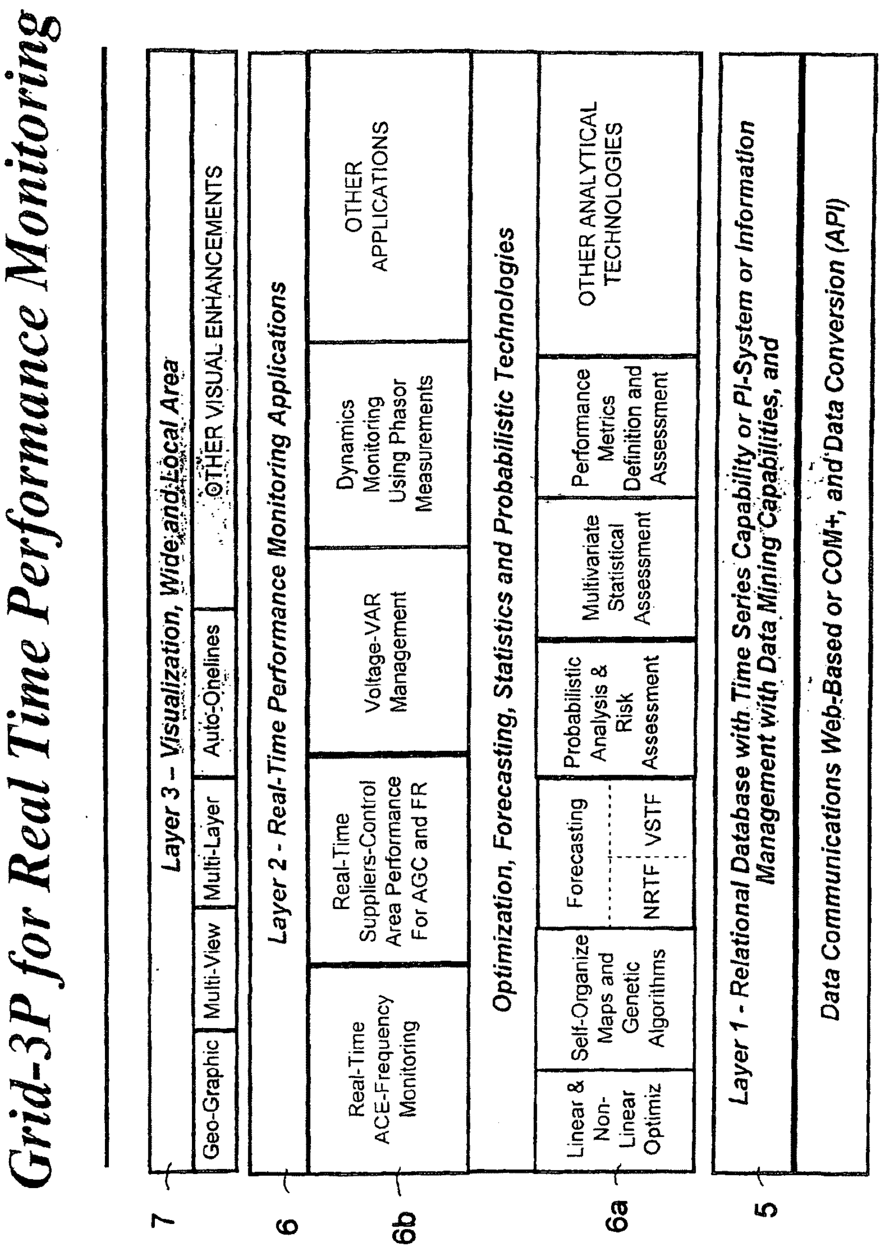

Grid-3P for Real Time Performance Monitoring
7
Layer 3 – Visualization, Wide and Local Area
Geo-Graphic
Multi-View
Multi-Layer
Auto-Onelines
OTHER VISUAL ENHANCEMENTS
6
Layer 2 - Real-Time Performance Monitoring Applications
6b
Real-Time ACE-Frequency Monitoring
Real-Time Suppliers-Control Area Performance For AGC and FR
Voltage-VAR Management
Dynamics Monitoring Using Phasor Measurements
OTHER APPLICATIONS
Optimization, Forecasting, Statistics and Probabilistic Technologies
6a
Linear & Non-Linear Optimiz
Self-Organize Maps and Genetic Algorithms
Forecasting
NRTF
VSTF
Probabilistic Analysis & Risk Assessment
Multivariate Statistical Assessment
Performance Metrics Definition and Assessment
OTHER ANALYTICAL TECHNOLOGIES
5
Layer 1 - Relational Database with Time Series Capability or PI-System or Information Management with Data Mining Capabilities, and
Data Communications Web-Based or COM+, and Data Conversion (API)

FIG. 4

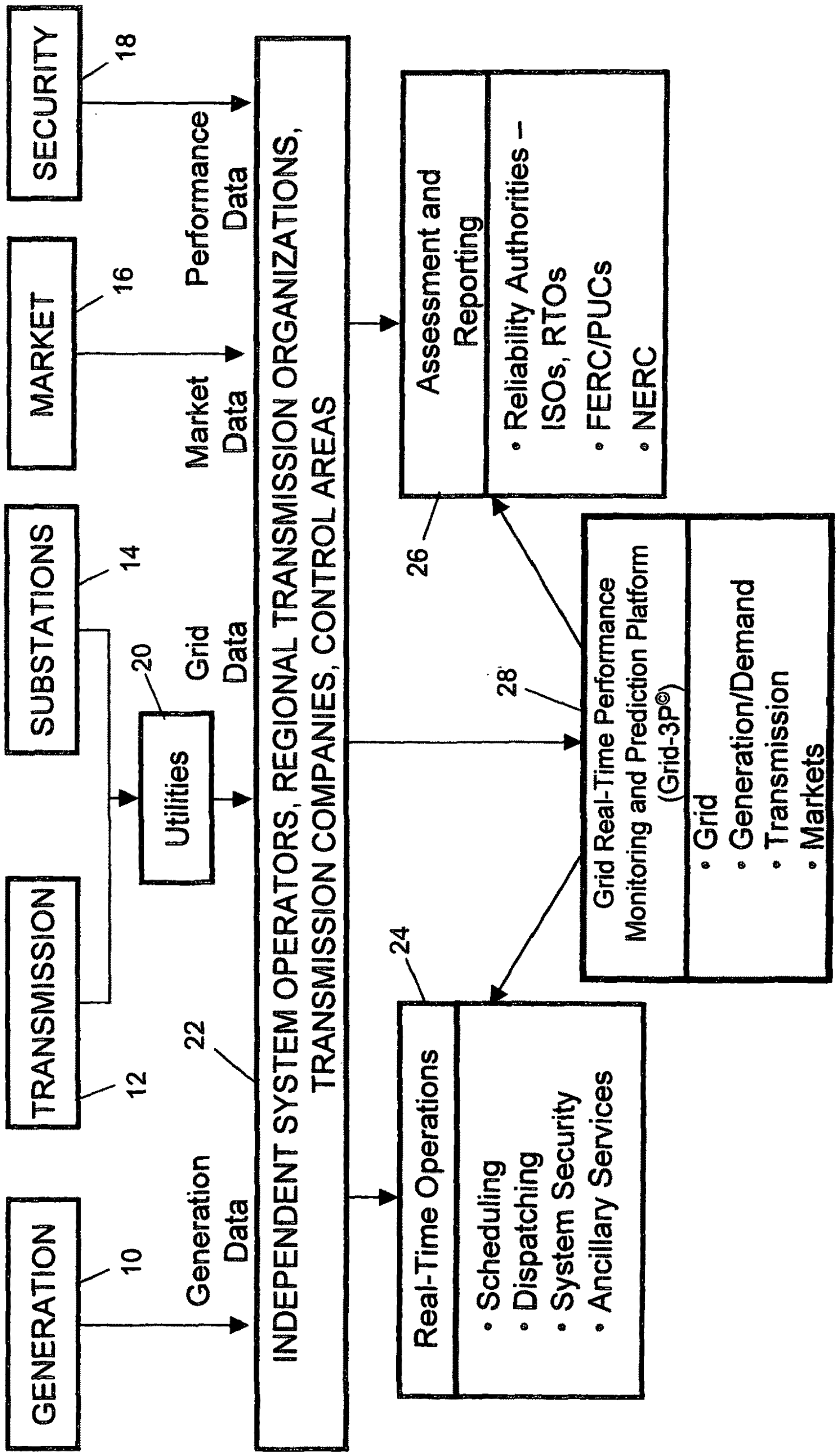

GENERATION
10
TRANSMISSION
12
SUBSTATIONS
14
MARKET
16
SECURITY
18
Generation Data
Utilities
20
Grid Data
Market Data
Performance Data
22
INDEPENDENT SYSTEM OPERATORS, REGIONAL TRANSMISSION ORGANIZATIONS, TRANSMISSION COMPANIES, CONTROL AREAS
24
Real-Time Operations
• Scheduling
• Dispatching
• System Security
• Ancillary Services
28
Grid Real-Time Performance Monitoring and Prediction Platform (Grid-3P©)
• Grid
• Generation/Demand
• Transmission
• Markets
26
Assessment and Reporting
• Reliability Authorities – ISOs, RTOs
• FERC/PUCs
• NERC

FIG. 5

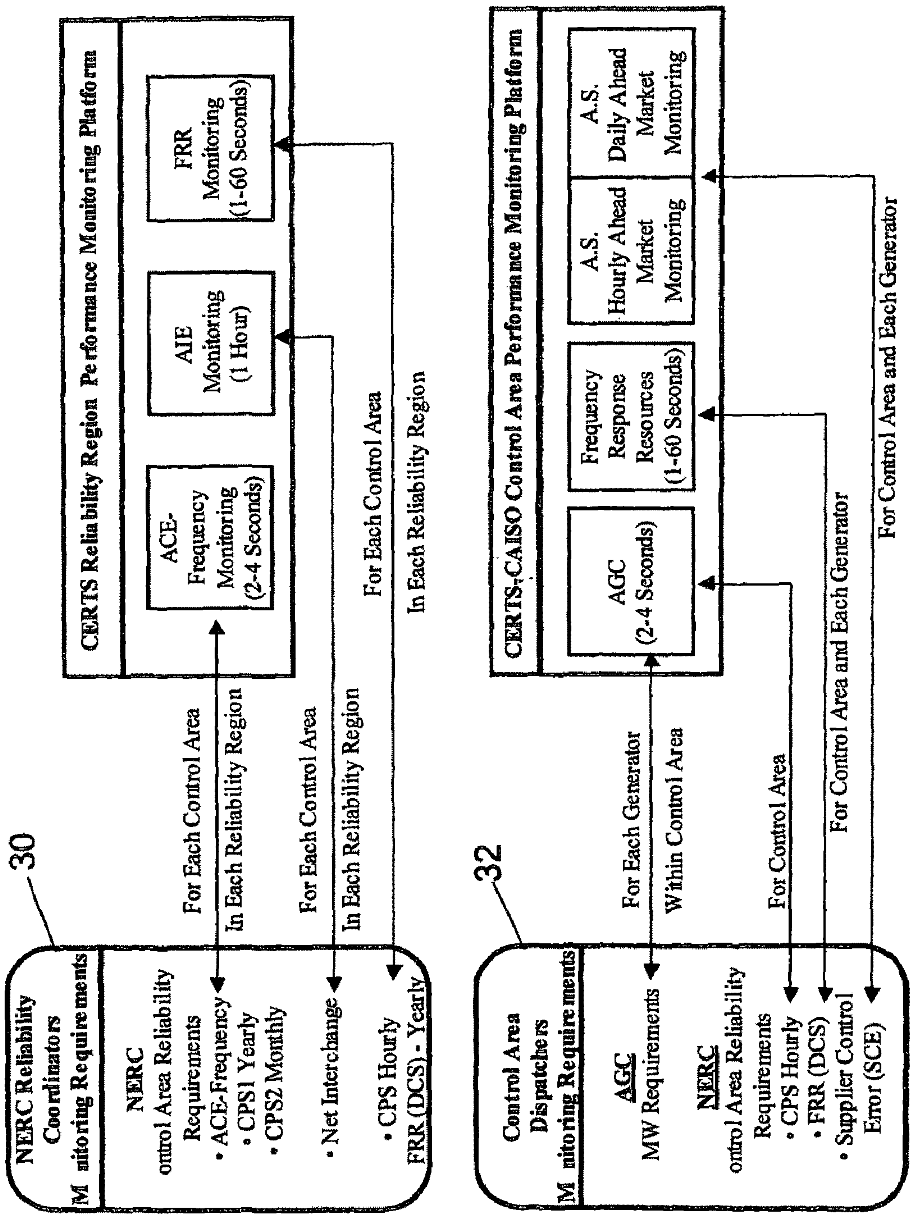

30
NERC Reliability Coordinators M nitoring Requirements
NERC
ontrol Area Reliability Requirements
• ACE-Frequency
• CPS1 Yearly
• CPS2 Monthly
• Net Interchange
• CPS Hourly
FRR (DCS) - Yearly
For Each Control Area
In Each Reliability Region
For Each Control Area
In Each Reliability Region
For Each Control Area
In Each Reliability Region
CERTS Reliability Region Performance Monitoring Platform
ACE-Frequency Monitoring (2-4 Seconds)
AIE Monitoring (1 Hour)
FRR Monitoring (1-60 Seconds)
32
Control Area Dispatchers M nitoring Requirements
AGC
MW Requirements
NERC
ontrol Area Reliability Requirements
• CPS Hourly
• FRR (DCS)
• Supplier Control Error (SCE)
For Each Generator
Within Control Area
For Control Area
For Control Area and Each Generator
For Control Area and Each Generator
CERTS-CAISO Control Area Performance Monitoring Platform
AGC (2-4 Seconds)
Frequency Response Resources (1-60 Seconds)
A.S. Hourly Ahead Market Monitoring
A.S. Daily Ahead Market Monitoring

FIG. 6

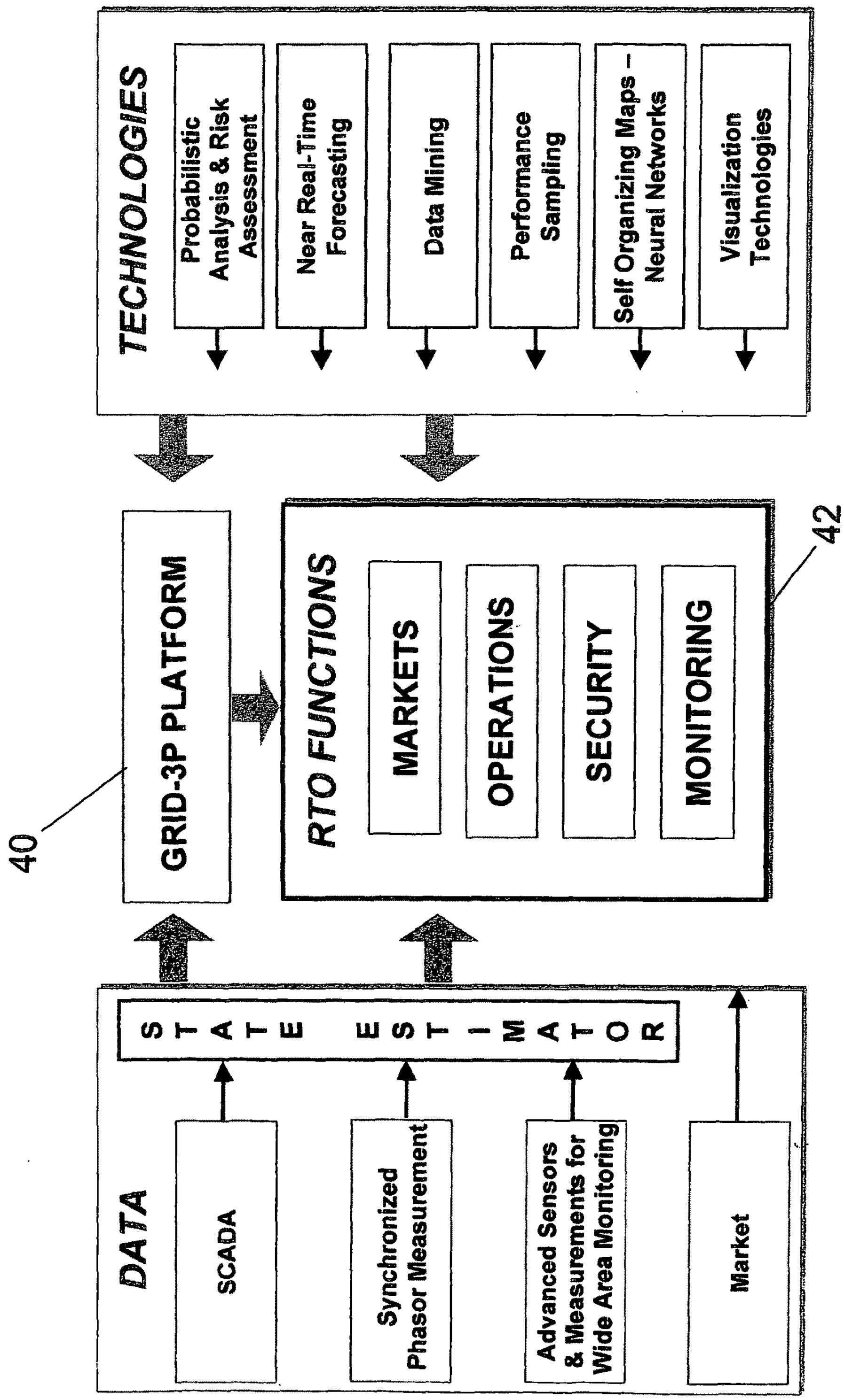
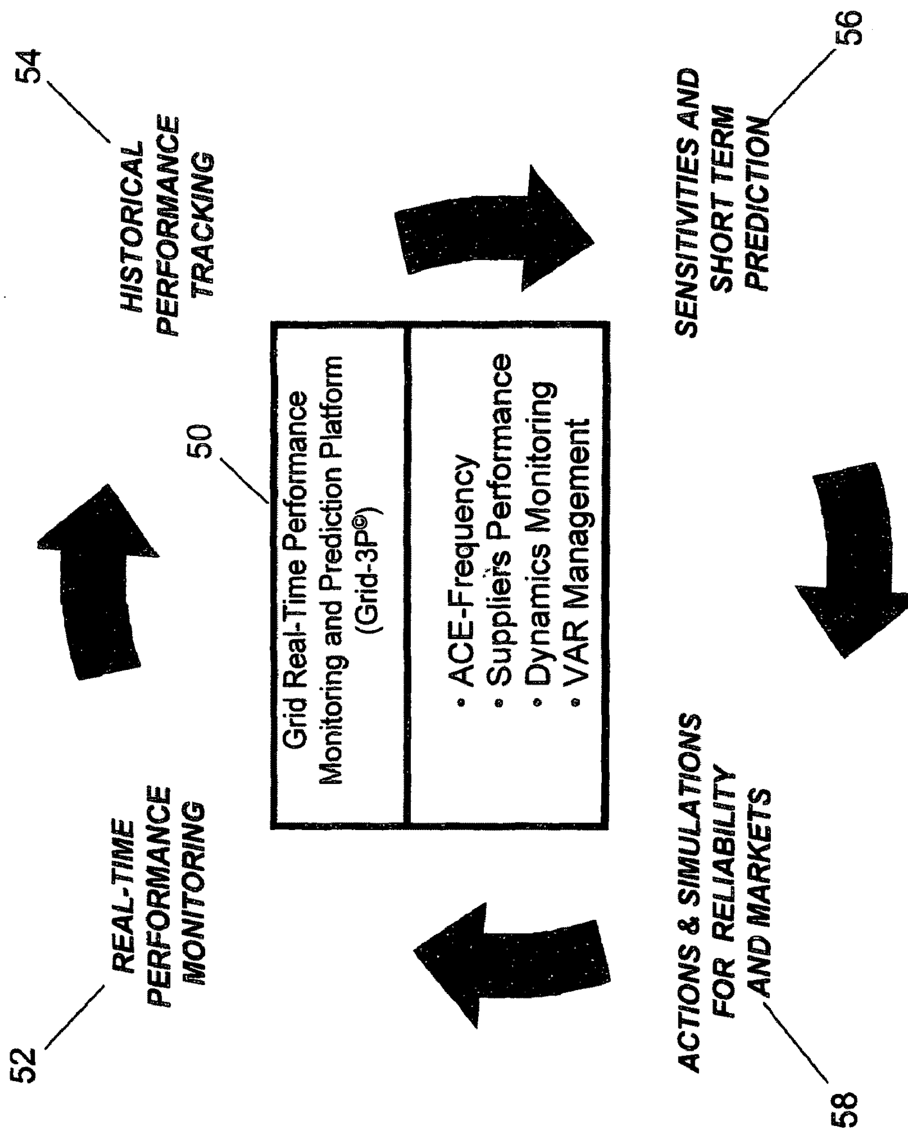

TECHNOLOGIES
Probabilistic Analysis & Risk Assessment
Near Real-Time Forecasting
Data Mining
Performance Sampling
Self Organizing Maps – Neural Networks
Visualization Technologies
GRID-3P PLATFORM
40
RTO FUNCTIONS
MARKETS
OPERATIONS
SECURITY
MONITORING
42
DATA
STATE ESTIMATOR
SCADA
Synchronized Phasor Measurement
Advanced Sensors & Measurements for Wide Area Monitoring
Market

FIG. 7



54
HISTORICAL PERFORMANCE TRACKING
56
SENSITIVITIES AND SHORT TERM PREDICTION
50
Grid Real-Time Performance Monitoring and Prediction Platform (Grid-3P©)
• ACE-Frequency
• Suppliers Performance
• Dynamics Monitoring
• VAR Management
52
REAL-TIME PERFORMANCE MONITORING
58
ACTIONS & SIMULATIONS FOR RELIABILITY AND MARKETS

FIG. 8

FIG. 9

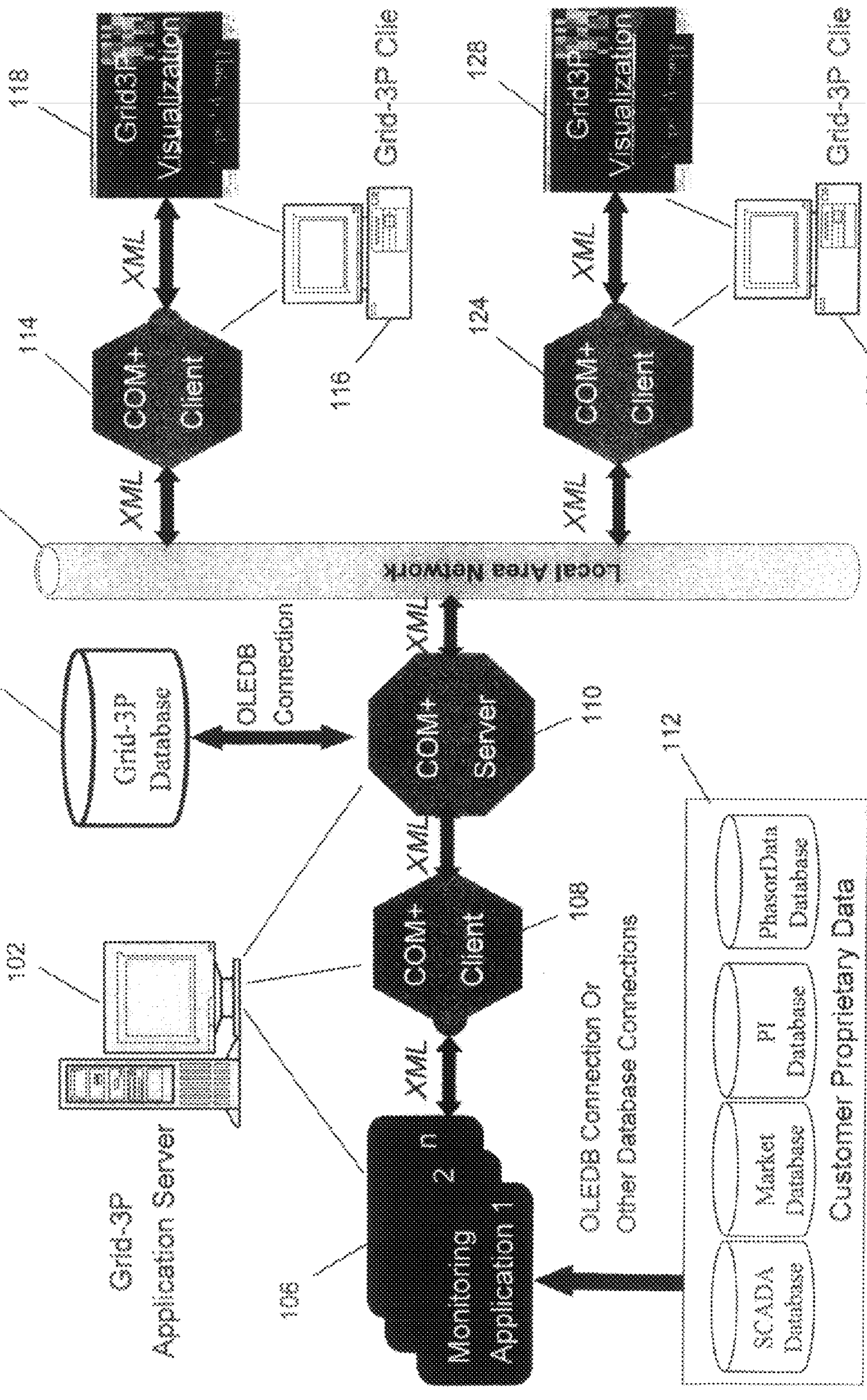
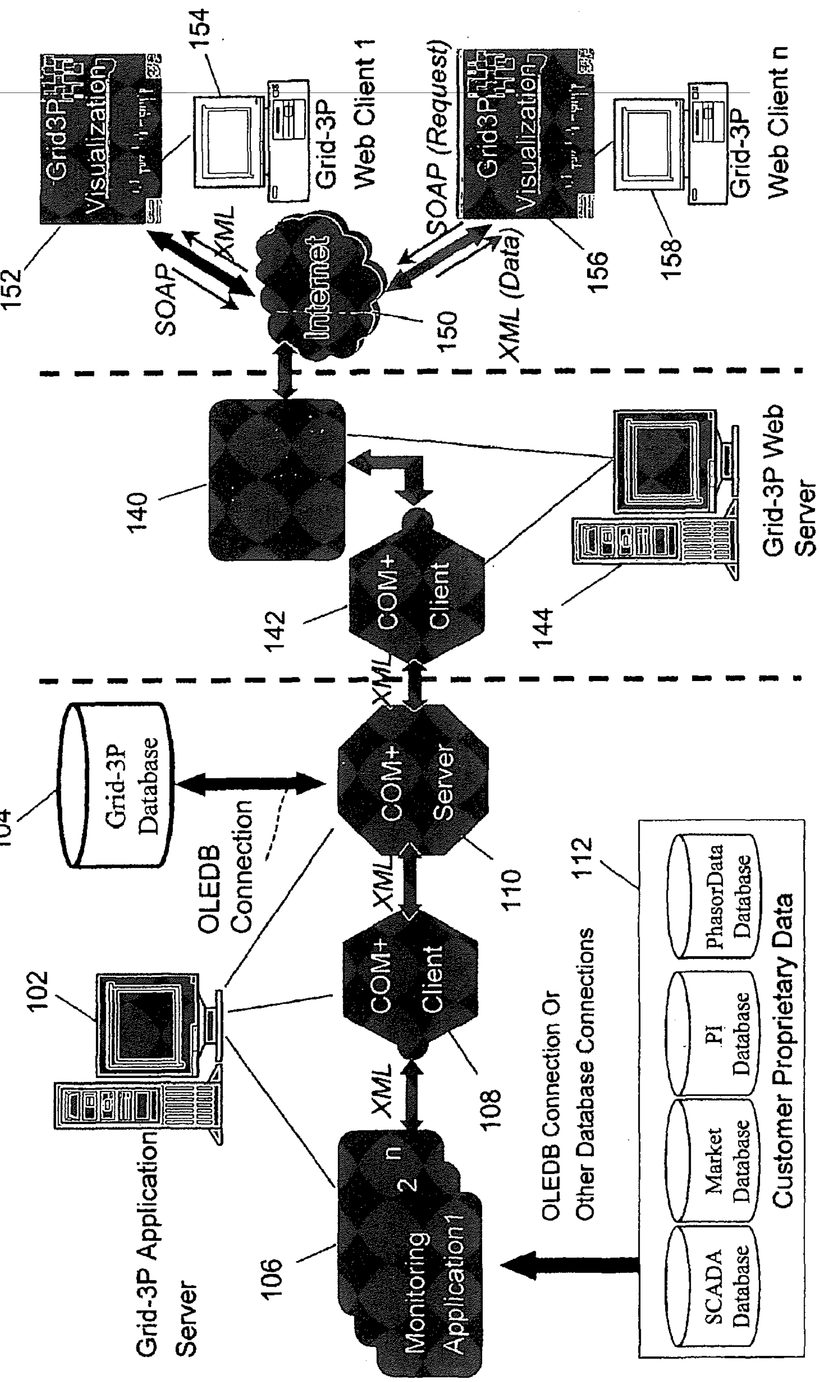

Grid-3P
Application Server
102
104
Grid-3P
Database
OLEDB
Connection
100
Local Area Network
XML
COM+
Client
108
COM+
Server
110
Monitoring
Application 1
2
n
106
OLEDB Connection Or
Other Database Connections
112
SCADA
Database
Market
Database
PI
Database
PhasorData
Database
Customer Proprietary Data
114
COM+
Client
116
118
Grid3P
Visualization
Grid-3P Clie
124
COM+
Client
126
128
Grid3P
Visualization
Grid-3P Clie

FIG. 10



Grid3P Visualization
154
Grid-3P Web Client 1
152
SOAP
XML
Internet
150
SOAP (Request)
XML (Data)
Grid3P Visualization
156
158
Grid-3P Web Client n
140
142
COM+ Client
144
Grid-3P Web Server
104
Grid-3P Database
OLEDB Connection
XML
COM+ Server
XML
110
112
102
COM+ Client
108
XML
Grid-3P Application Server
106
Monitoring Application1
2
n
OLEDB Connection Or Other Database Connections
SCADA Database
Market Database
PI Database
PhasorData Database
Customer Proprietary Data

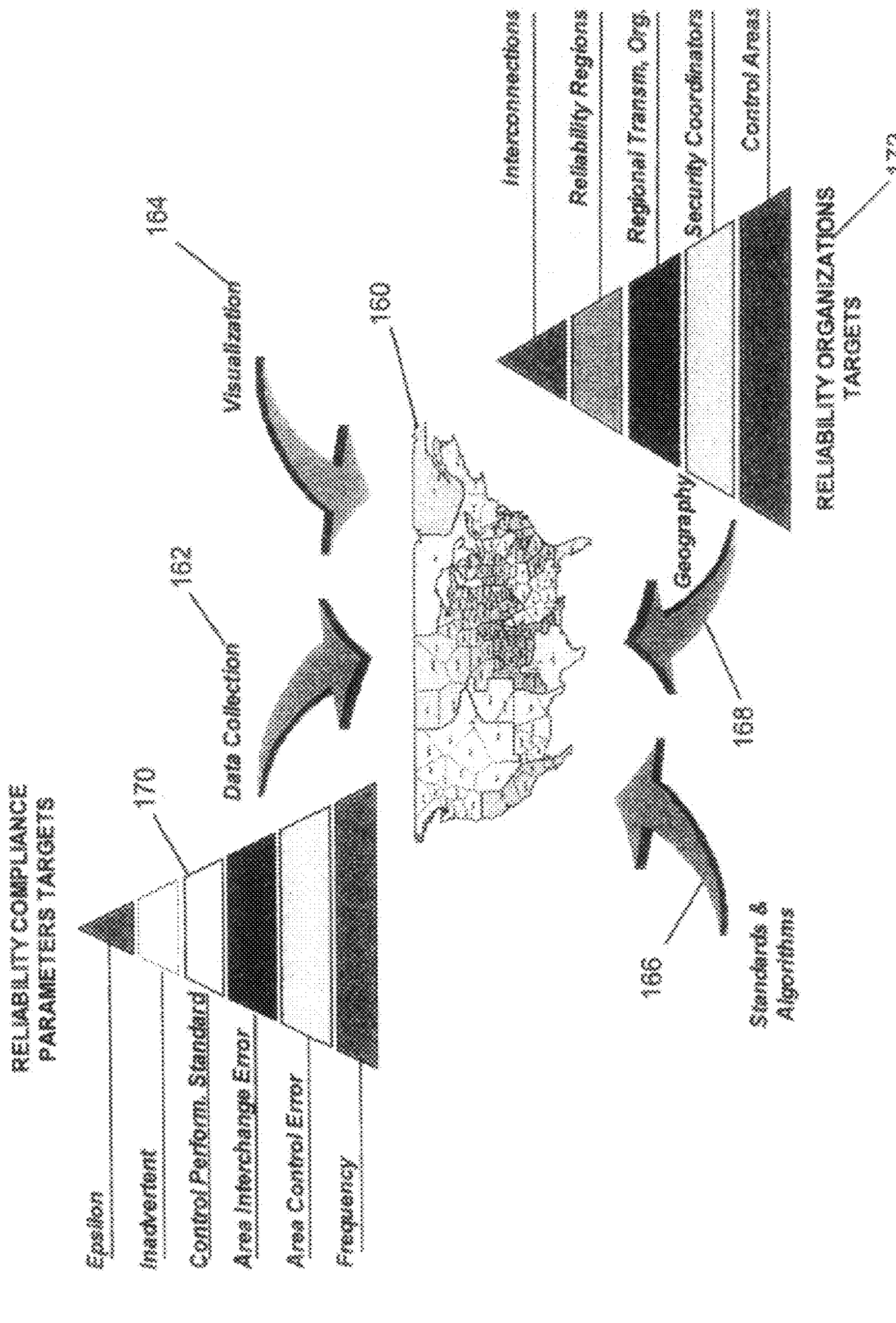
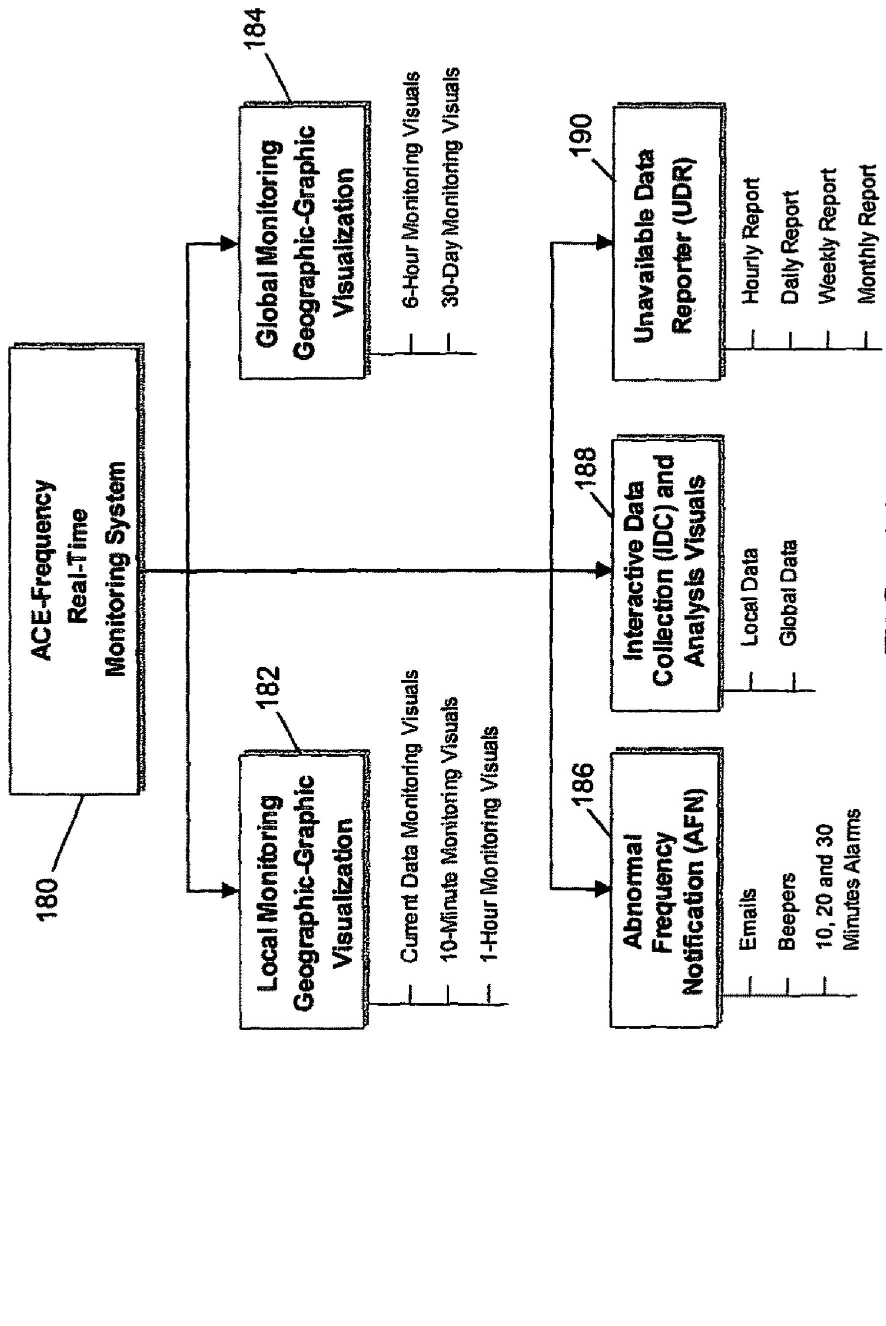

RELIABILITY COMPLIANCE PARAMETERS TARGETS
170
Epsilon
Inadvertent
Control Perform. Standard
Area Interchange Error
Area Control Error
Frequency
Data Collection
162
Visualization
164
160
Interconnections
Reliability Regions
Regional Transm. Org.
Security Coordinators
Control Areas
172
RELIABILITY ORGANIZATIONS TARGETS
Geography
168
166
Standards & Algorithms

FIG. 11



180
ACE-Frequency Real-Time Monitoring System
182
Local Monitoring Geographic-Graphic Visualization
Current Data Monitoring Visuals
10-Minute Monitoring Visuals
1-Hour Monitoring Visuals
184
Global Monitoring Geographic-Graphic Visualization
6-Hour Monitoring Visuals
30-Day Monitoring Visuals
186
Abnormal Frequency Notification (AFN)
Emails
Beepers
10, 20 and 30 Minutes Alarms
188
Interactive Data Collection (IDC) and Analysis Visuals
Local Data
Global Data
190
Unavailable Data Reporter (UDR)
Hourly Report
Daily Report
Weekly Report
Monthly Report

FIG. 12

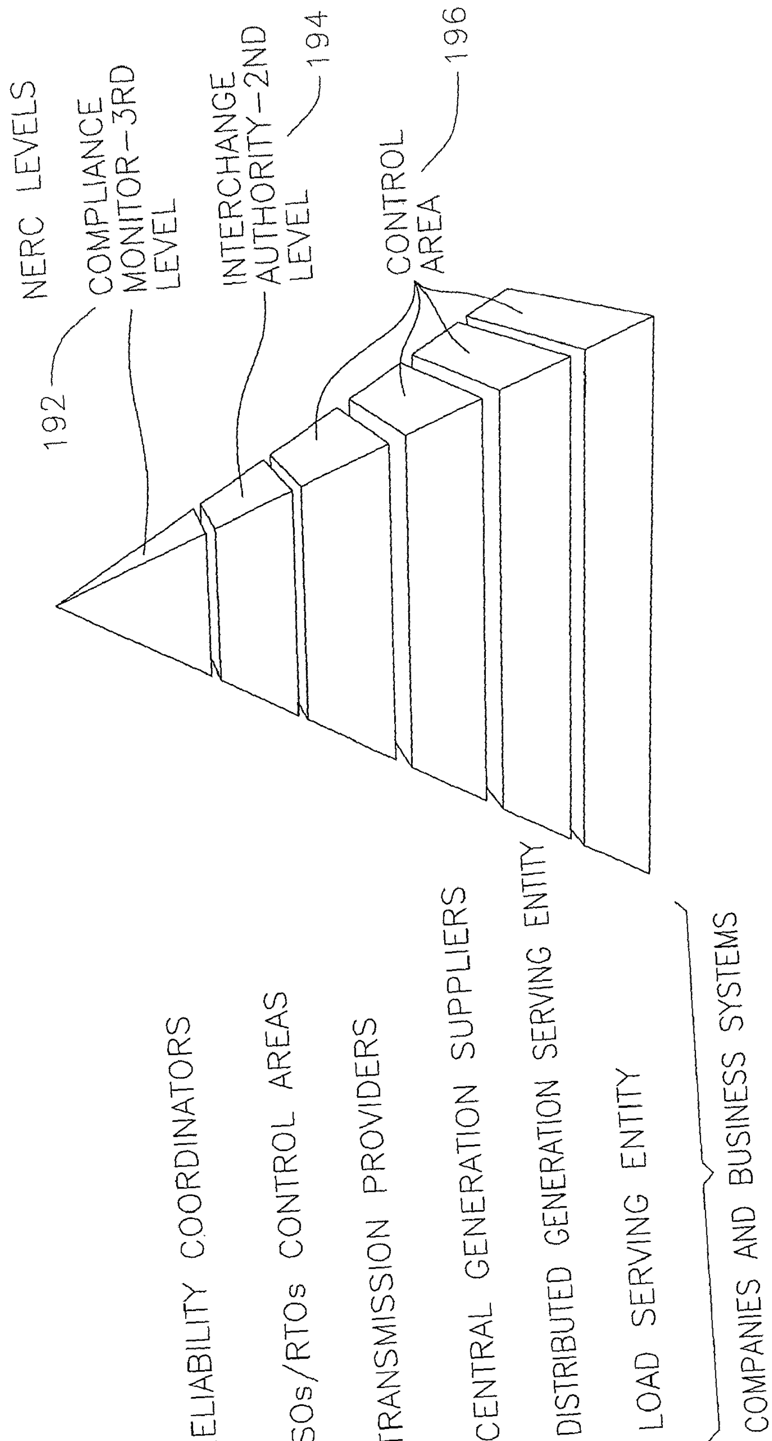

NERC LEVELS
COMPLIANCE MONITOR—3RD LEVEL
INTERCHANGE AUTHORITY—2ND LEVEL
CONTROL AREA
192
194
196
RELIABILITY COORDINATORS
ISOs/RTOs CONTROL AREAS
TRANSMISSION PROVIDERS
CENTRAL GENERATION SUPPLIERS
DISTRIBUTED GENERATION SERVING ENTITY
LOAD SERVING ENTITY
COMPANIES AND BUSINESS SYSTEMS

FIG.13

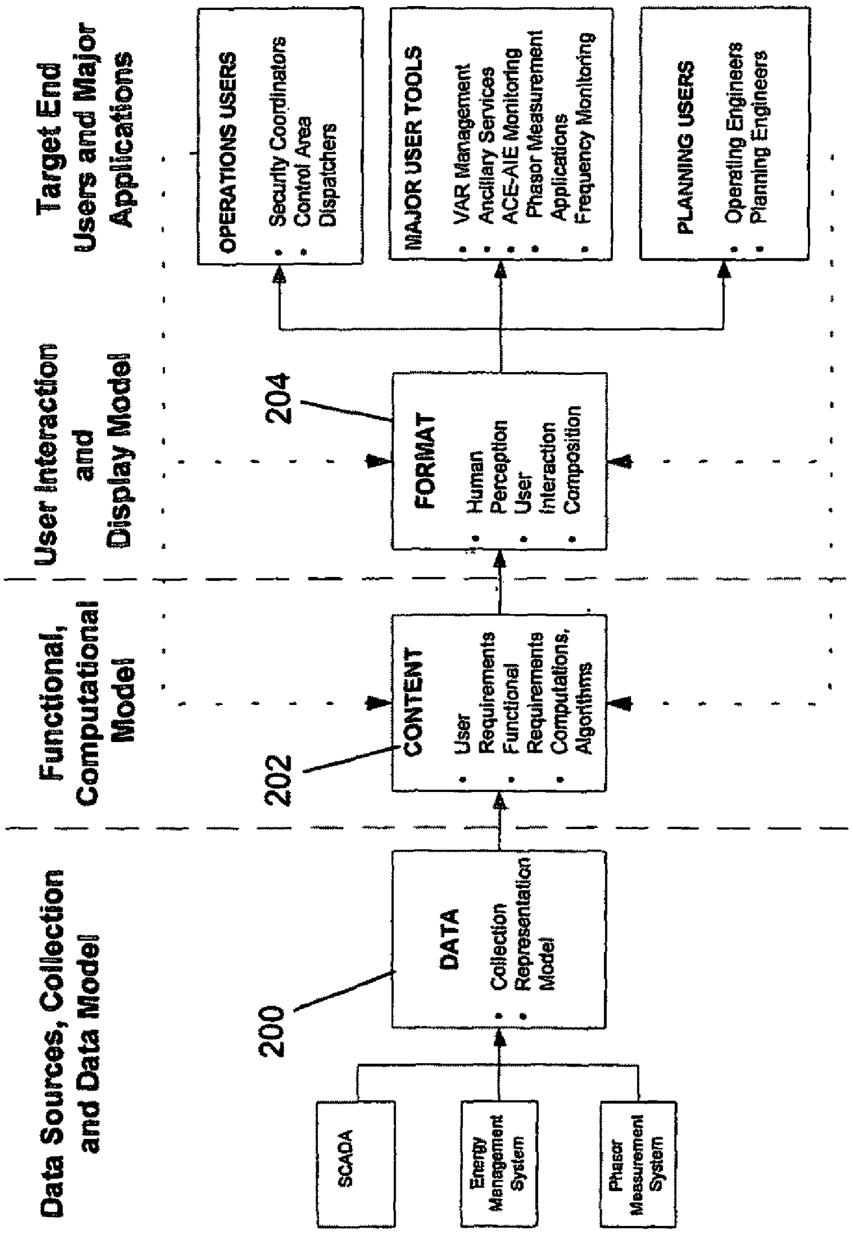

Data Sources, Collection and Data Model
Functional, Computational Model
User Interaction and Display Model
Target End Users and Major Applications
SCADA
Energy Management System
Phasor Measurement System
200
DATA
• Collection
• Representation Model
202
CONTENT
• User Requirements
• Functional Requirements
• Computations, Algorithms
204
FORMAT
• Human Perception
• User Interaction
• Composition
OPERATIONS USERS
• Security Coordinators
• Control Area Dispatchers
MAJOR USER TOOLS
• VAR Management
• Ancillary Services
• ACE-AIE Monitoring
• Phasor Measurement Applications
• Frequency Monitoring
PLANNING USERS
• Operating Engineers
• Planning Engineers

FIG. 14

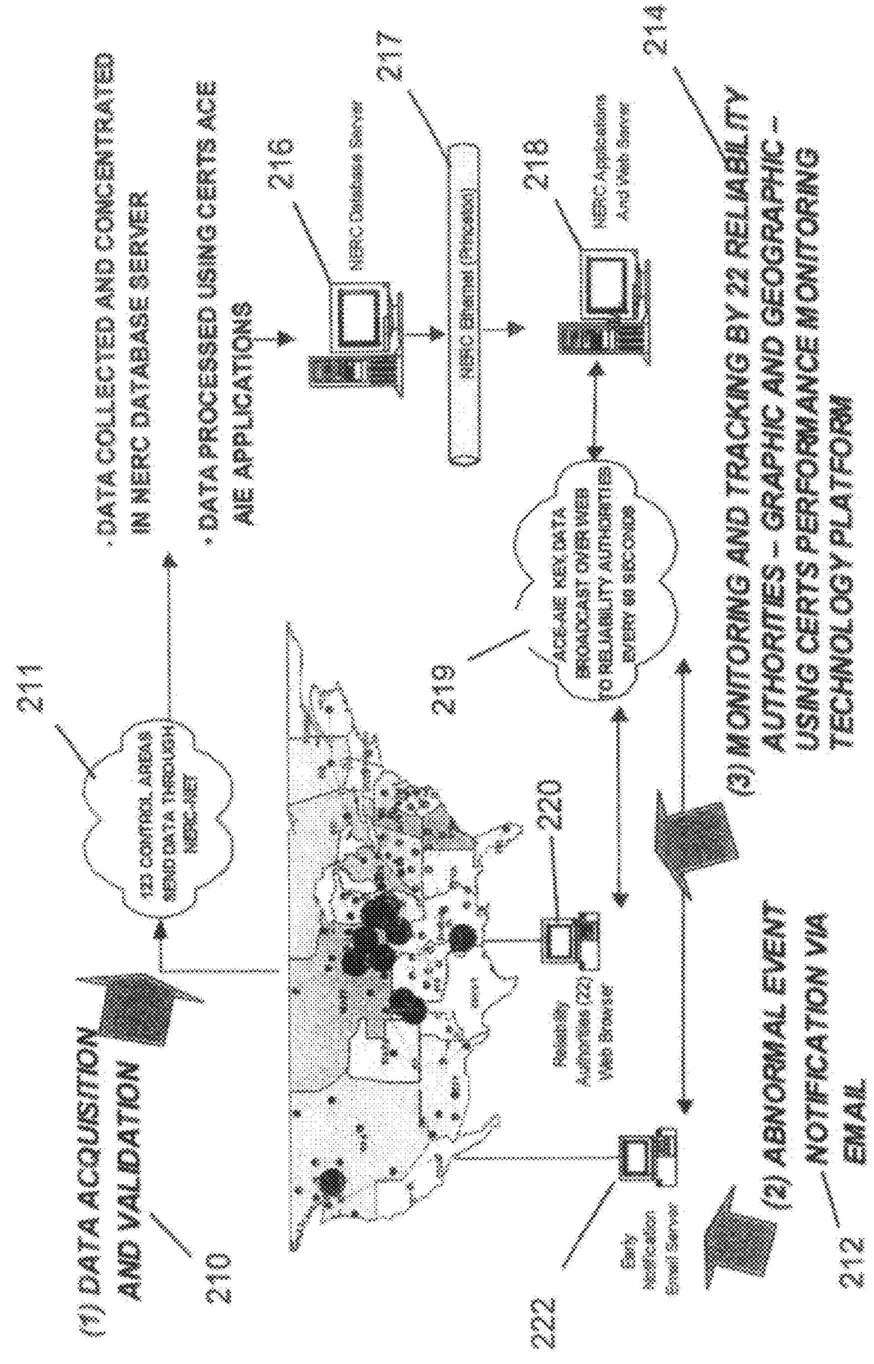
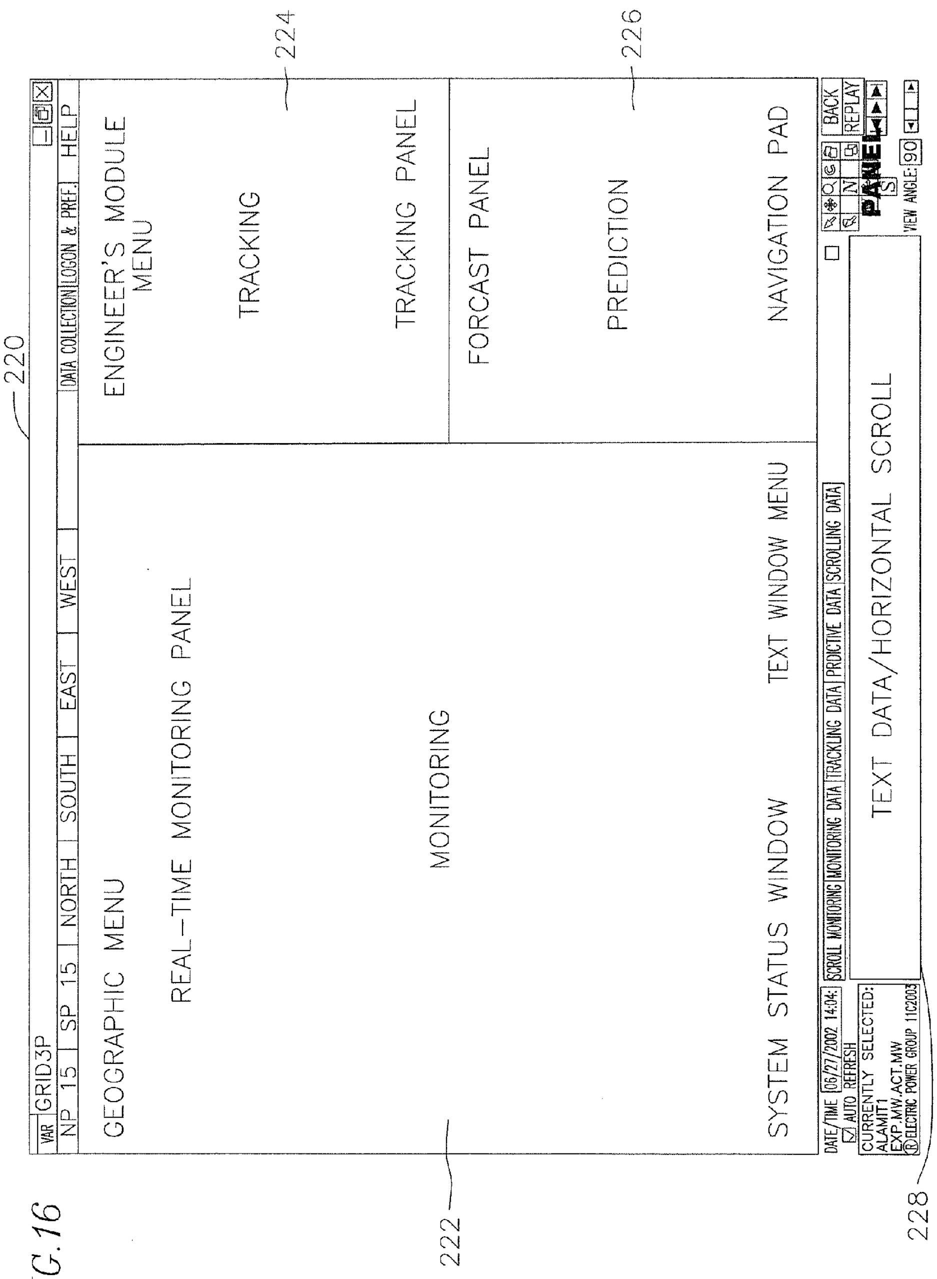

(1) DATA ACQUISITION AND VALIDATION
210
211
· DATA COLLECTED AND CONCENTRATED IN NERC DATABASE SERVER
· DATA PROCESSED USING CERTS ACE AIE APPLICATIONS
216
217
218
214
219
220
222
(3) MONITORING AND TRACKING BY 22 RELIABILITY AUTHORITIES – GRAPHIC AND GEOGRAPHIC – USING CERTS PERFORMANCE MONITORING TECHNOLOGY PLATFORM
(2) ABNORMAL EVENT NOTIFICATION VIA EMAIL
212

FIG. 15

FIG.16


220
222
224
226
228
GRID3P
NP 15
SP 15
NORTH
SOUTH
EAST
WEST
DATA COLLECTION
LOGON & PREF.
HELP
GEOGRAPHIC MENU
REAL-TIME MONITORING PANEL
MONITORING
SYSTEM STATUS WINDOW
TEXT WINDOW MENU
ENGINEER'S MODULE MENU
TRACKING
TRACKING PANEL
FORCAST PANEL
PREDICTION
NAVIGATION PAD
DATE/TIME
06/27/2002 14:04:
AUTO REFRESH
CURRENTLY SELECTED:
ALAMIT1
EXP.MW.ACT.MW
SCROLL MONITORING
MONITORING DATA
TRACKLING DATA
PRDICTIVE DATA
SCROLLING DATA
TEXT DATA/HORIZONTAL SCROLL
BACK
REPLAY
PANEL
VIEW ANGLE: 90

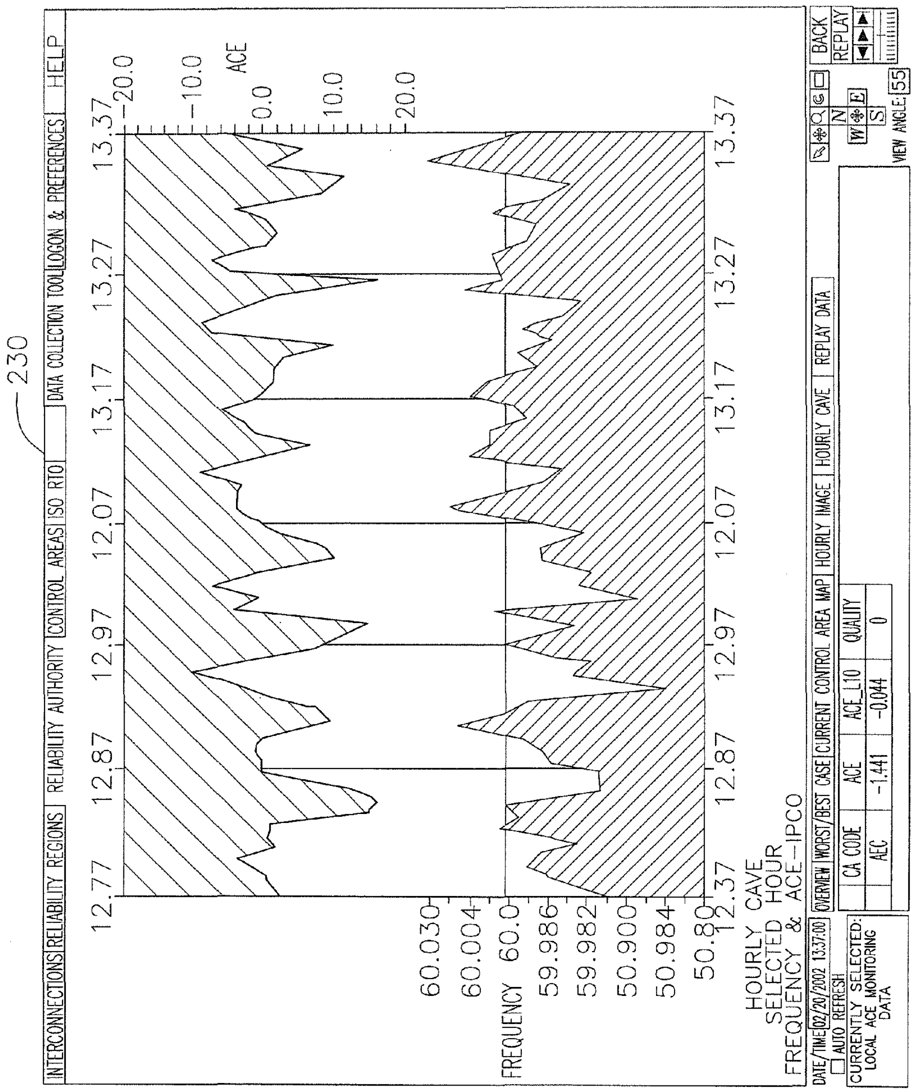

230
INTERCONNECTIONS
RELIABILITY REGIONS
RELIABILITY AUTHORITY
CONTROL AREAS
ISO RTO
DATA COLLECTION TOOL
LOGON & PREFERENCES
HELP
ACE
-20.0
-10.0
0.0
10.0
20.0
12.77
12.87
12.97
12.07
13.17
13.27
13.37
60.030
60.004
FREQUENCY 60.0
59.986
59.982
50.900
50.984
50.80
12.37
HOURLY CAVE
SELECTED HOUR
FREQUENCY & ACE-IPCO
DATE/TIME 02/20/2002 13:37:00
AUTO REFRESH
CURRENTLY SELECTED:
LOCAL ACE MONITORING DATA
OVERVIEW
WORST/BEST CASE
CURRENT CONTROL AREA MAP
HOURLY IMAGE
HOURLY CAVE
REPLAY DATA
CA CODE
ACE
ACE_L10
QUALITY
AEC
-1.441
-0.044
0
N
W
E
S
VIEW ANGLE: 55
BACK
REPLAY

FIG. 17

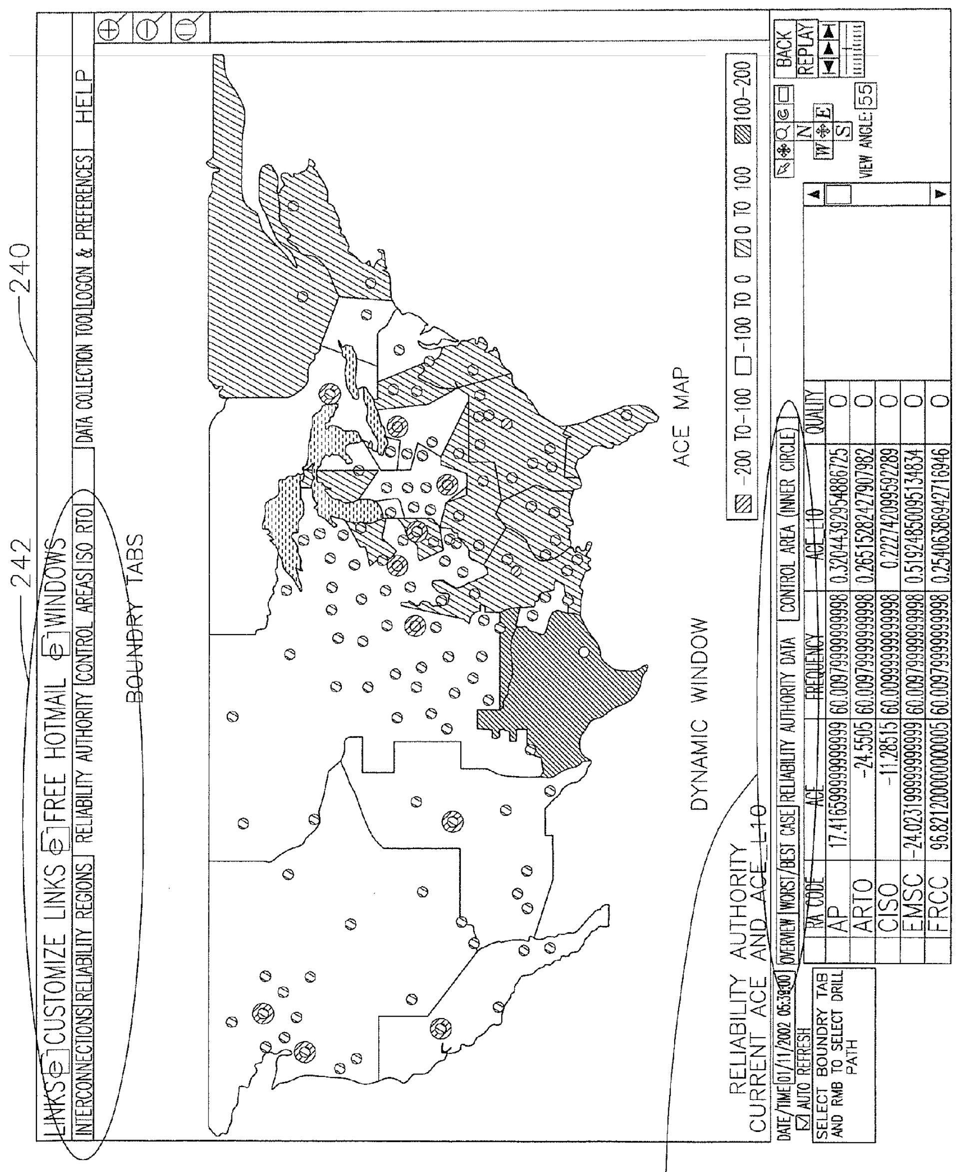
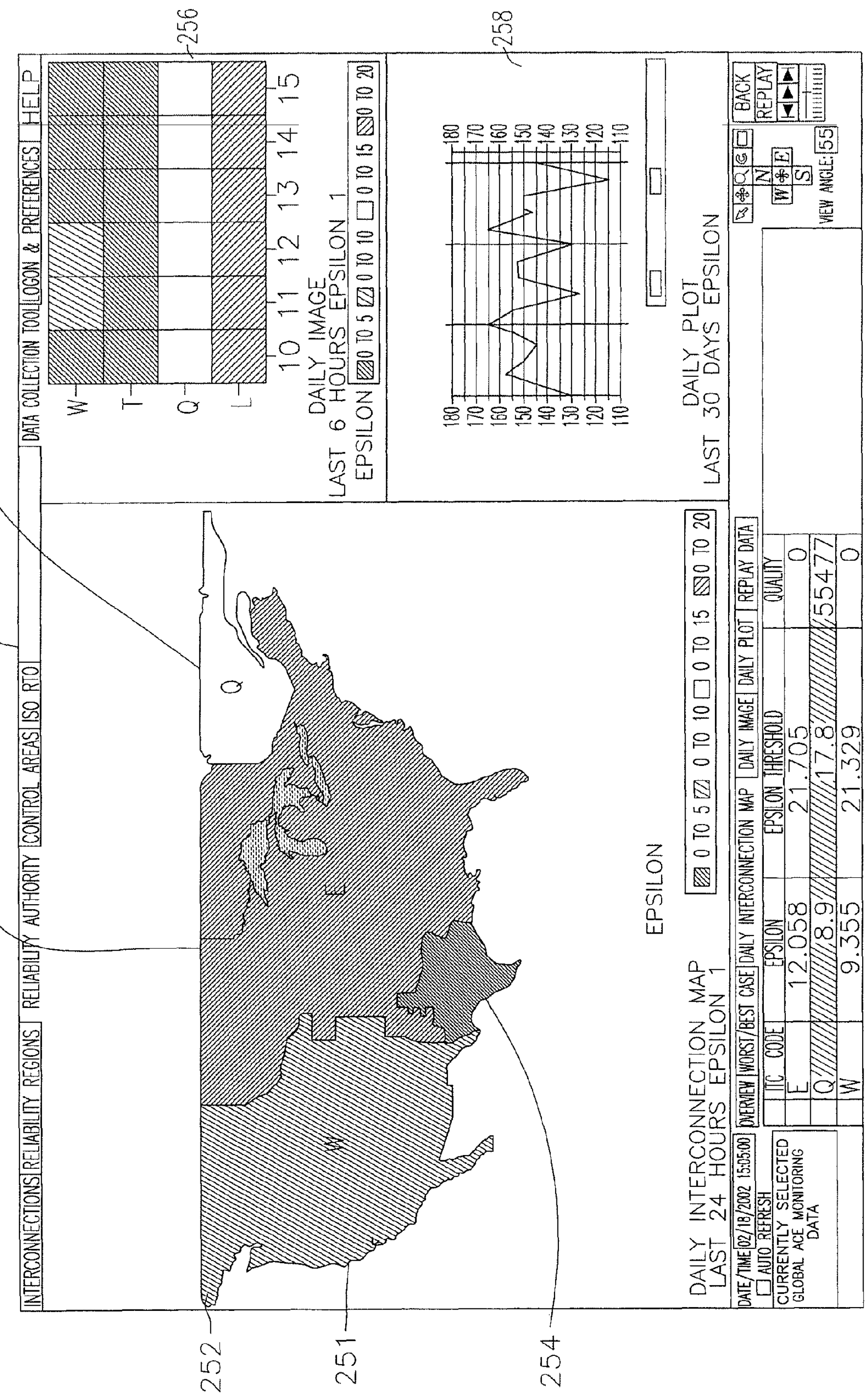

240
242
244
LINKS CUSTOMIZE LINKS FREE HOTMAIL WINDOWS
INTERCONNECTIONS RELIABILITY REGIONS RELIABILITY AUTHORITY CONTROL AREAS ISO RTO DATA COLLECTION TOOL LOGON & PREFERENCES HELP
BOUNDRY TABS
ACE MAP
DYNAMIC WINDOW
RELIABILITY AUTHORITY
CURRENT ACE AND ACE_L10
-200 TO -100 -100 TO 0 0 TO 100 100-200
DATE/TIME 01/11/2002 05:39:00
AUTO REFRESH
SELECT BOUNDRY TAB AND RMB TO SELECT DRILL PATH
OVERVIEW WORST/BEST CASE RELIABILITY AUTHORITY DATA CONTROL AREA (INNER CIRCLE)
RA CODE ACE FREQUENCY ACE_L10 QUALITY
AP 17.41659999999999 60.00979999999998 0.32044392954886725 0
ARTO -24.5505 60.00979999999998 0.2651528242790798 0
CISO -11.28515 60.00999999999998 0.22274209959282 0
EMSC -24.02319999999999 60.00979999999998 0.51924850095134834 0
FRCC 96.82120000000005 60.00979999999998 0.25406386942716946 0
BACK REPLAY
N W E S
VIEW ANGLE: 55

FIG.18

FIG.19


INTERCONNECTIONS
RELIABILITY REGIONS
RELIABILITY AUTHORITY
CONTROL AREAS
ISO RTO
DATA COLLECTION TOOL
LOGON & PREFERENCES
HELP
DAILY INTERCONNECTION MAP
LAST 24 HOURS EPSILON 1
EPSILON
DAILY IMAGE
LAST 6 HOURS EPSILON 1
DAILY PLOT
LAST 30 DAYS EPSILON
EPSILON THRESHOLD
QUALITY
CURRENTLY SELECTED
GLOBAL ACE MONITORING
DATA
BACK
REPLAY
VIEW ANGLE:
250
251
252
253
254
255
256
258

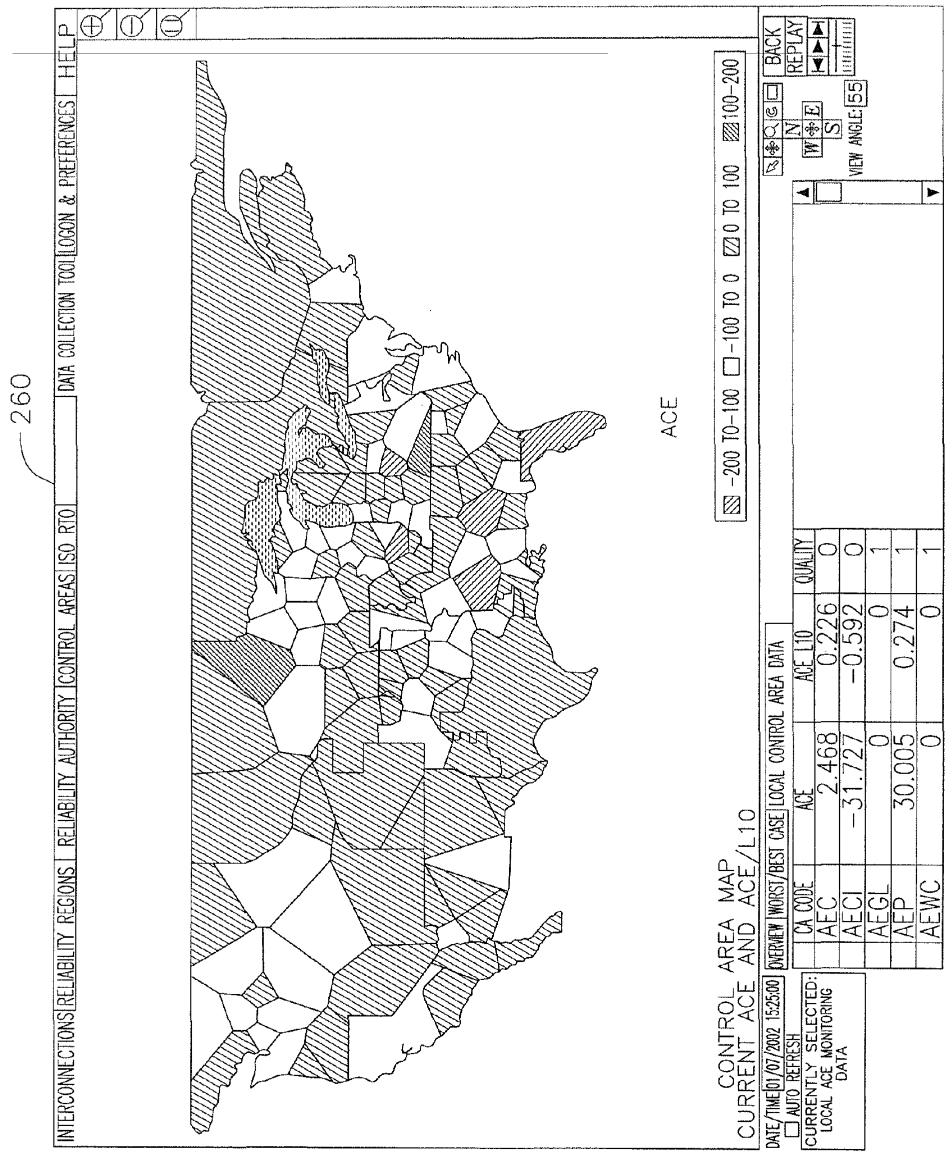
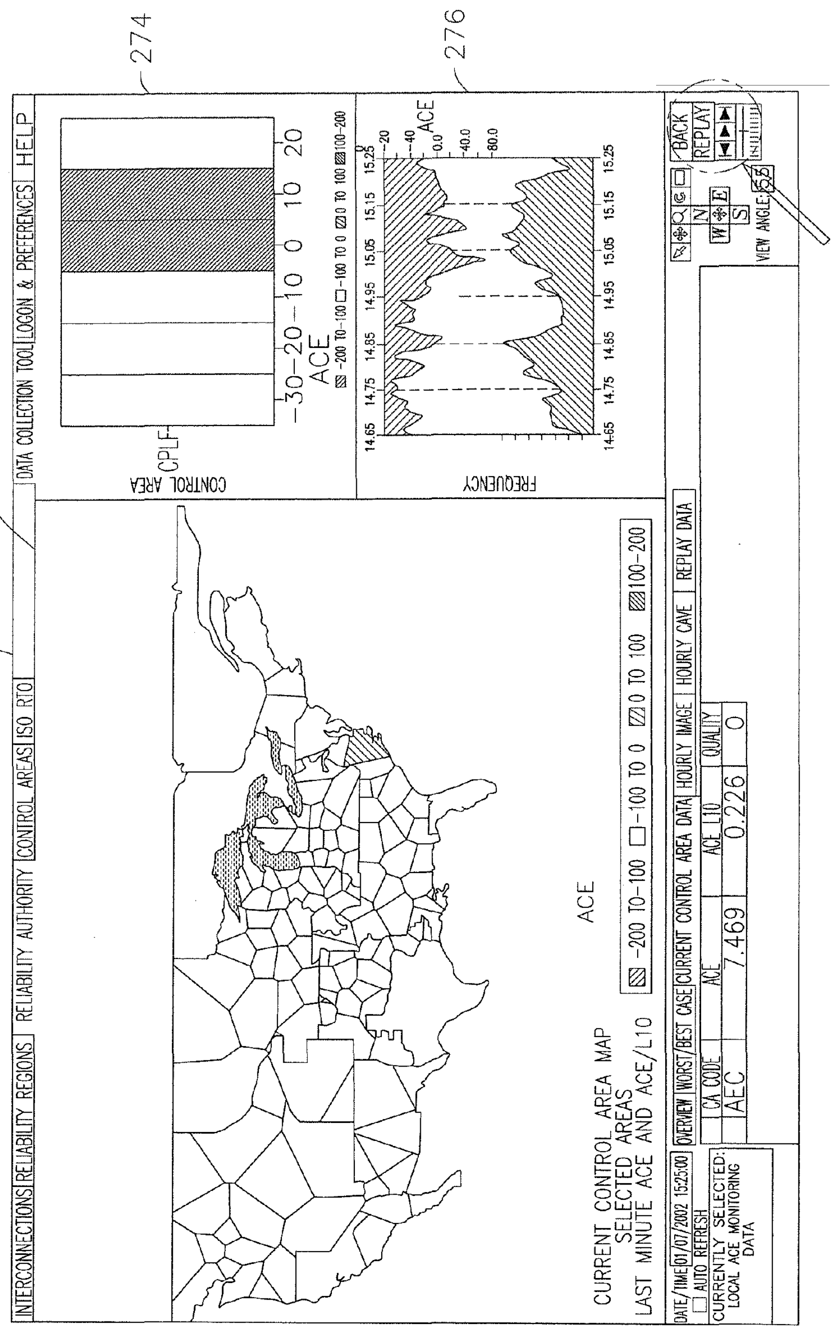
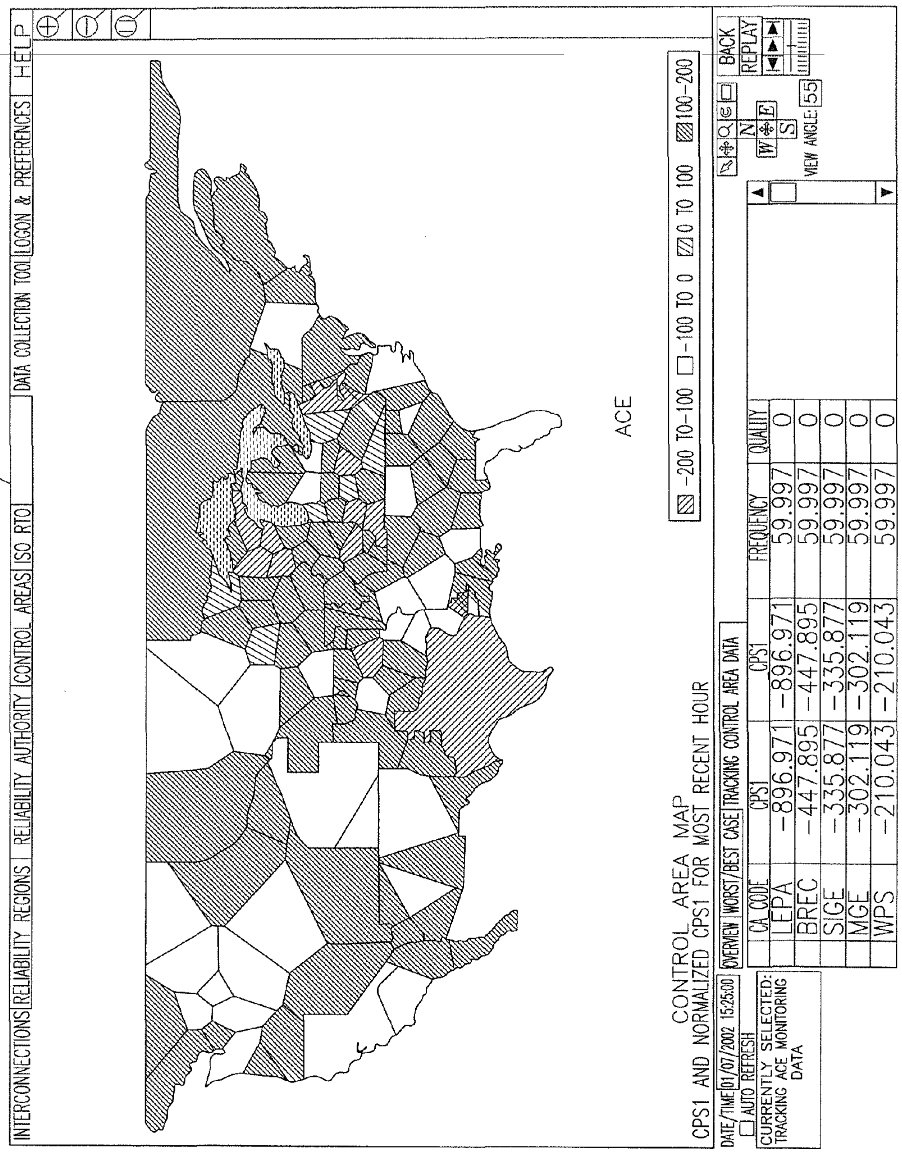

260
INTERCONNECTIONS
RELIABILITY REGIONS
RELIABILITY AUTHORITY
CONTROL AREAS
ISO RTO
DATA COLLECTION TOOL
LOGON & PREFERENCES
HELP
ACE
-200 TO-100
-100 TO 0
0 TO 100
100-200
CONTROL AREA MAP
CURRENT ACE AND ACE/L10
DATE/TIME 01/07/2002 15:25:00
AUTO REFRESH
CURRENTLY SELECTED:
LOCAL ACE MONITORING DATA
OVERVIEW
WORST/BEST CASE
LOCAL CONTROL AREA DATA
CA CODE
ACE
ACE L10
QUALITY
AEC 2.468 0.226 0
AECI -31.727 -0.592 0
AEGL 0 0 1
AEP 30.005 0.274 1
AEWC 0 0 1
N
W
E
S
VIEW ANGLE: 55
BACK
REPLAY

FIG. 20

FIG. 21


270
272
274
276
INTERCONNECTIONS
RELIABILITY REGIONS
RELIABILITY AUTHORITY
CONTROL AREAS
ISO RTO
DATA COLLECTION TOOL
LOGON & PREFERENCES
HELP
CONTROL AREA
CPLF
ACE
FREQUENCY
CURRENT CONTROL AREA MAP
SELECTED AREAS
LAST MINUTE ACE AND ACE/L10
-200 TO-100
-100 TO 0
0 TO 100
100-200
DATE/TIME 01/07/2002 15:25:00
AUTO REFRESH
CURRENTLY SELECTED: LOCAL ACE MONITORING DATA
OVERVIEW
WORST/BEST CASE
CURRENT CONTROL AREA DATA
HOURLY IMAGE
HOURLY CAVE
REPLAY DATA
CA CODE
ACE
ACE L10
QUALITY
AEC
7.469
0.226
0
BACK
REPLAY
N
W
E
S
VIEW ANGLE: 55

280

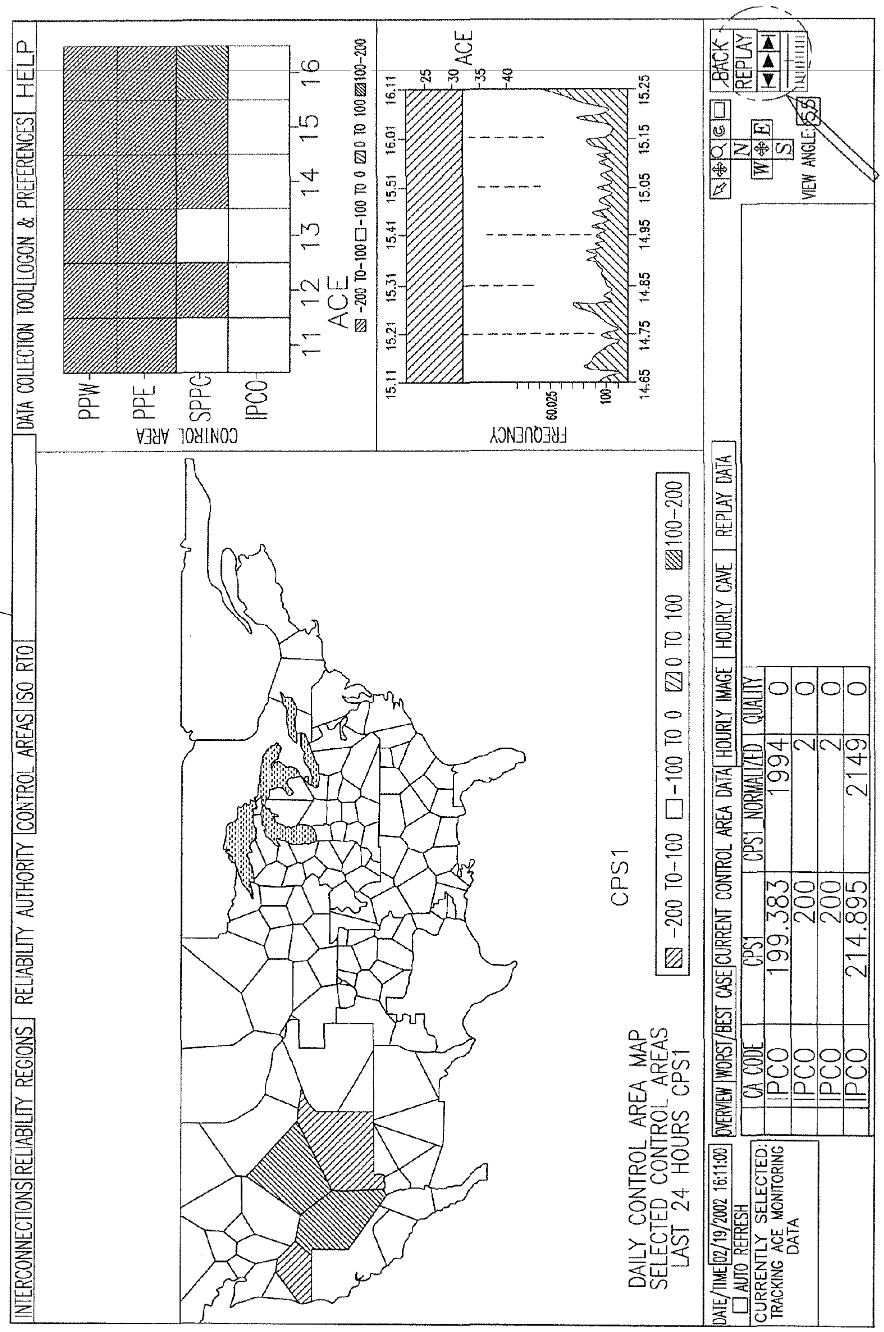


INTERCONNECTIONS
RELIABILITY REGIONS
RELIABILITY AUTHORITY
CONTROL AREAS
ISO RTO
DATA COLLECTION TOOL
LOGON & PREFERENCES
HELP
ACE
-200 TO-100
-100 TO 0
0 TO 100
100-200
CONTROL AREA MAP
CPS1 AND NORMALIZED CPS1 FOR MOST RECENT HOUR
DATE/TIME 01/07/2002 15:25:00
AUTO REFRESH
CURRENTLY SELECTED: TRACKING ACE MONITORING DATA
OVERVIEW
WORST/BEST CASE
TRACKING CONTROL AREA DATA
CA CODE | CPS1 | CPS1 | FREQUENCY | QUALITY
LEPA | -896.971 | -896.971 | 59.997 | 0
BREC | -447.895 | -447.895 | 59.997 | 0
SIGE | -335.877 | -335.877 | 59.997 | 0
MGE | -302.119 | -302.119 | 59.997 | 0
WPS | -210.043 | -210.043 | 59.997 | 0
BACK
REPLAY
N
W
E
S
VIEW ANGLE: 55

FIG. 22

FIG. 23

290


INTERCONNECTIONS
RELIABILITY REGIONS
RELIABILITY AUTHORITY
CONTROL AREAS
ISO RTO
DATA COLLECTION TOOL
LOGON & PREFERENCES
HELP
DAILY CONTROL AREA MAP
SELECTED CONTROL AREAS
LAST 24 HOURS CPS1
CPS1
-200 TO-100 □-100 TO 0 ▨0 TO 100 ▨100-200
CONTROL AREA
PPW
PPE
SPPG
IPCO
11 12 13 14 15 16
ACE
FREQUENCY
ACE
BACK
REPLAY
N
W
E
S
VIEW ANGLE:
DATE/TIME 02/19/2002 16:11:00
AUTO REFRESH
CURRENTLY SELECTED: TRACKING ACE MONITORING DATA
OVERVIEW
WORST/BEST CASE
CURRENT CONTROL AREA DATA
HOURLY IMAGE
HOURLY CAVE
REPLAY DATA
CA CODE
CPS1
CPS1 NORMALIZED
QUALITY
IPCO 199.383 1994 0
IPCO 200 2 0
IPCO 200 2 0
IPCO 214.895 2149 0

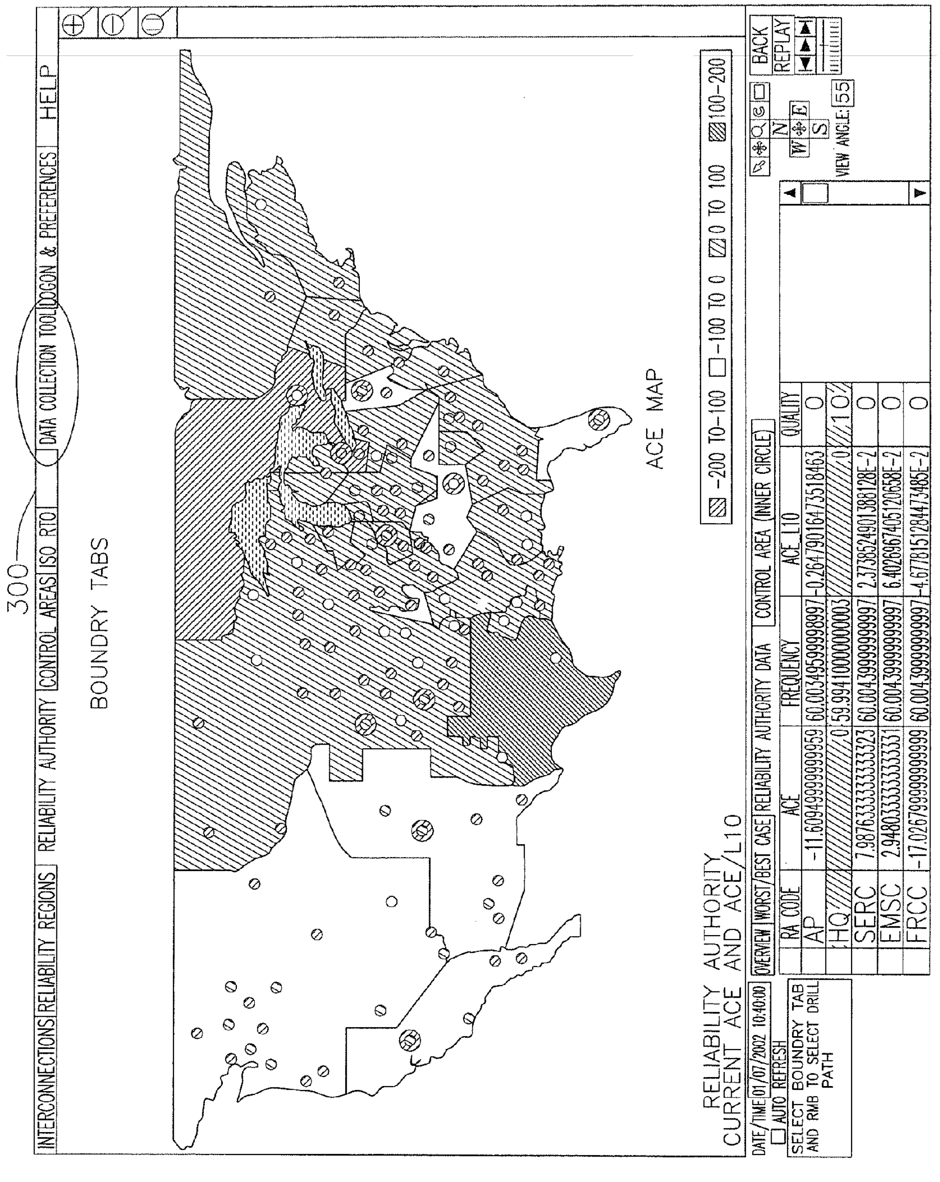

300
INTERCONNECTIONS
RELIABILITY REGIONS
RELIABILITY AUTHORITY
CONTROL AREAS
ISO RTO
DATA COLLECTION TOOL
POLYGON & PREFERENCES
HELP
BOUNDRY TABS
ACE MAP
-200 TO -100
-100 TO 0
0 TO 100
100-200
RELIABILITY AUTHORITY
CURRENT ACE AND ACE/L10
DATE/TIME 01/07/2002 10:40:00
AUTO REFRESH
SELECT BOUNDRY TAB AND RMB TO SELECT DRILL PATH
OVERVIEW
WORST/BEST CASE
RELIABILITY AUTHORITY DATA
CONTROL AREA (INNER CIRCLE)
RA CODE | ACE | FREQUENCY | ACE_L10 | QUALITY
AP | -11.609499999999959 | 60.003495999998997 | -0.26479016473518463 | 0
HQ | 0 | 59.994100000000003 | 0 | 10
SERC | 7.9876333333333323 | 60.004399999999997 | 2.3738524901388128E-2 | 0
EMSC | 2.9480333333333331 | 60.004399999999997 | 6.4026967405120658E-2 | 0
FRCC | -17.026799999999999 | 60.004399999999997 | -4.6778151284473485E-2 | 0
N
W
E
S
VIEW ANGLE 55
BACK
REPLAY

FIG. 24

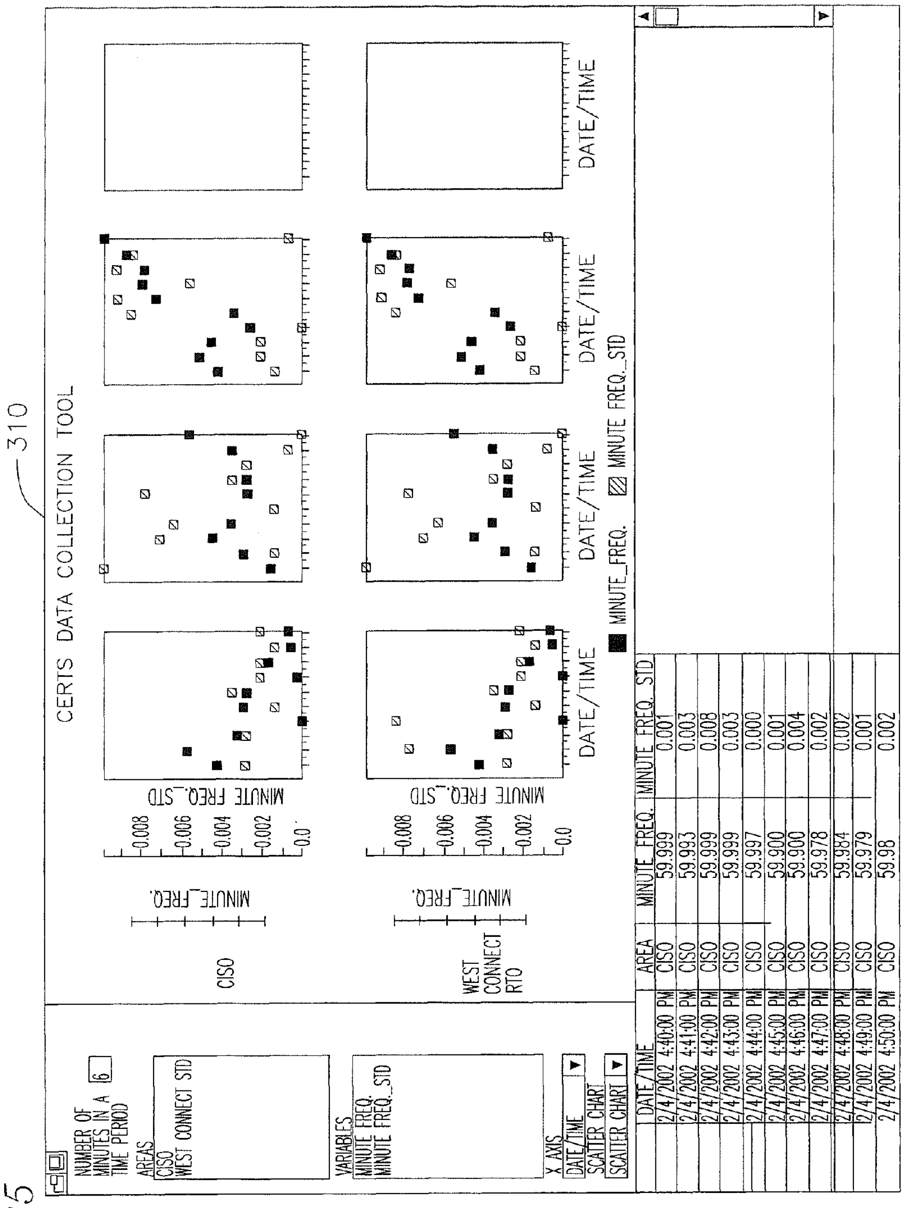

310
CERTS DATA COLLECTION TOOL
NUMBER OF MINUTES IN A TIME PERIOD
6
AREAS
CISO
WEST CONNECT STD
VARIABLES
MINUTE FREQ.
MINUTE FREQ._STD
X AXIS
DATE/TIME
SCATTER CHART
SCATTER CHART
CISO
WEST CONNECT RTO
MINUTE_FREQ.
MINUTE FREQ._STD
0.008
0.006
0.004
0.002
0.0
DATE/TIME
MINUTE_FREQ.
MINUTE FREQ._STD
DATE/TIME
AREA
MINUTE_FREQ.
MINUTE_FREQ._STD
2/4/2002 4:40:00 PM CISO 59.999 0.001
2/4/2002 4:41:00 PM CISO 59.993 0.003
2/4/2002 4:42:00 PM CISO 59.999 0.008
2/4/2002 4:43:00 PM CISO 59.999 0.003
2/4/2002 4:44:00 PM CISO 59.997 0.000
2/4/2002 4:45:00 PM CISO 59.900 0.001
2/4/2002 4:46:00 PM CISO 59.900 0.004
2/4/2002 4:47:00 PM CISO 59.978 0.002
2/4/2002 4:48:00 PM CISO 59.984 0.002
2/4/2002 4:49:00 PM CISO 59.979 0.001
2/4/2002 4:50:00 PM CISO 59.98 0.002

FIG. 25

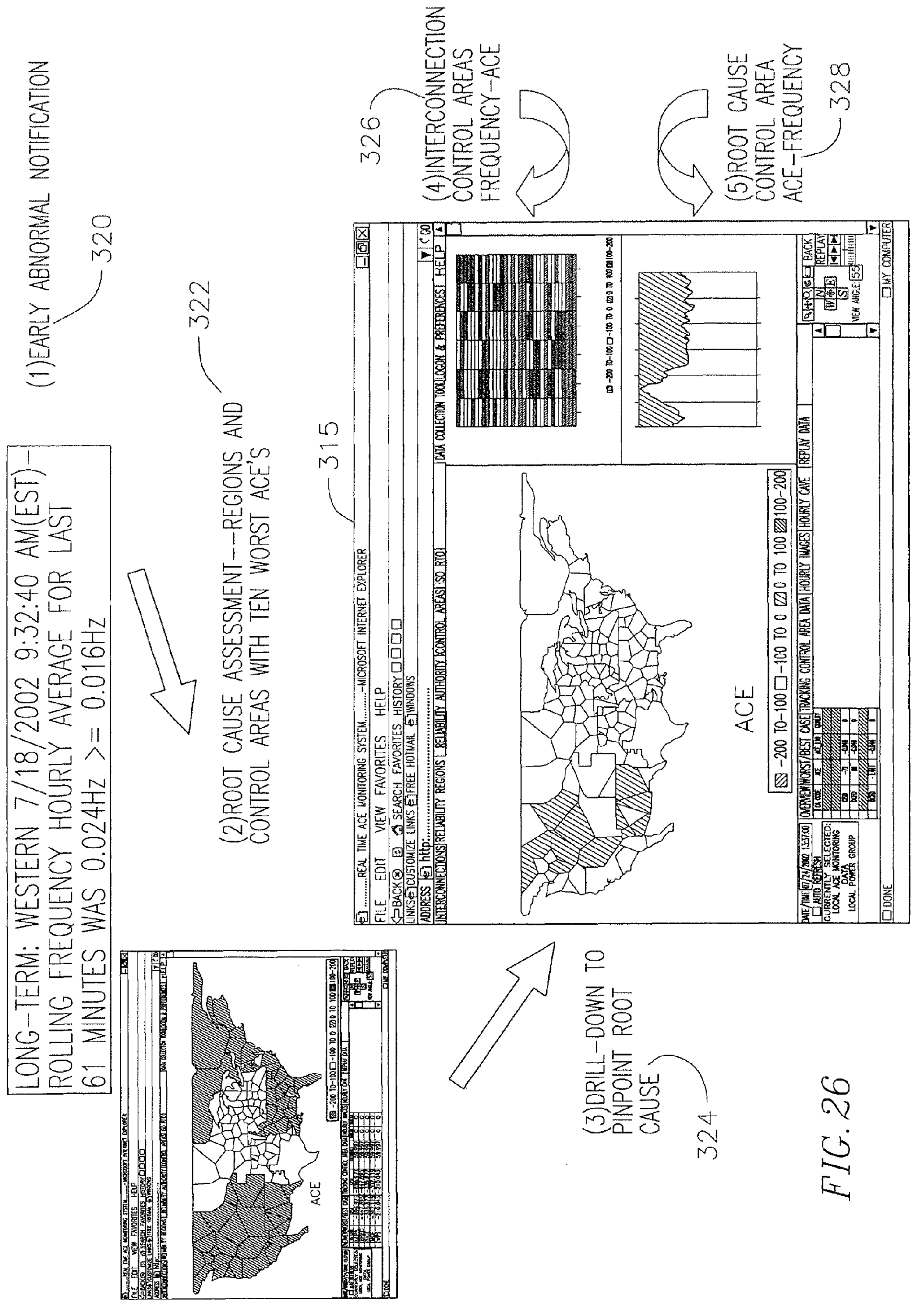
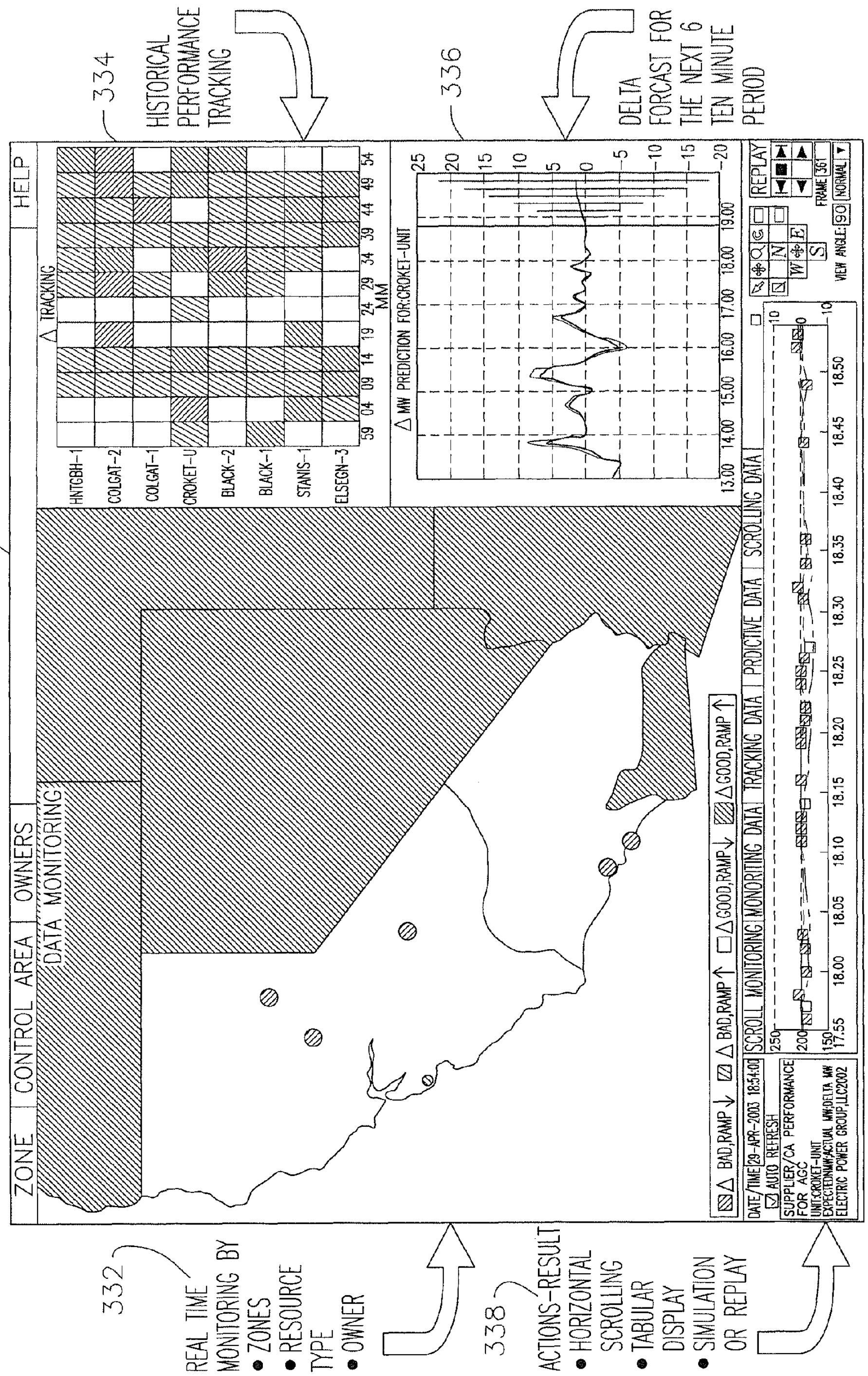

LONG-TERM: WESTERN 7/18/2002 9:32:40 AM(EST)-
ROLLING FREQUENCY HOURLY AVERAGE FOR LAST
61 MINUTES WAS 0.024Hz >= 0.016Hz
(1)EARLY ABNORMAL NOTIFICATION
320
(2)ROOT CAUSE ASSESSMENT--REGIONS AND CONTROL AREAS WITH TEN WORST ACE'S
322
315
(3)DRILL-DOWN TO PINPOINT ROOT CAUSE
324
(4)INTERCONNECTION CONTROL AREAS FREQUENCY-ACE
326
(5)ROOT CAUSE CONTROL AREA ACE-FREQUENCY
328
REAL TIME ACE MONITORING SYSTEM.........-MICROSOFT INTERNET EXPLORER
FILE EDIT VIEW FAVORITES HELP
BACK SEARCH FAVORITES HISTORY
LINKS CUSTOMIZE LINKS FREE HOTMAIL WINDOWS
ADDRESS http:
INTERCONNECTIONS RELIABILITY REGIONS RELIABILITY AUTHORITY CONTROL AREAS ISO RTO
DATA COLLECTION TOOL LOGIN & PREFERENCES HELP
ACE
-200 TO-100 -100 TO 0 0 TO 100 100-200
OVERVIEW WORST/BEST CASE TRACKING CONTROL AREA DATA HOURLY IMAGES HOURLY CAVE REPLAY DATA
CURRENTLY SELECTED: LOCAL ACE MONITORING DATA LOCAL POWER GROUP
BACK REPLAY
VIEW ANGLE
DONE
MY COMPUTER

FIG. 26

FIG. 27



330
334
HISTORICAL PERFORMANCE TRACKING
336
DELTA FORCAST FOR THE NEXT 6 TEN MINUTE PERIOD
332
REAL TIME MONITORING BY
• ZONES
• RESOURCE TYPE
• OWNER
338
ACTIONS-RESULT
• HORIZONTAL SCROLLING TABULAR DISPLAY
• SIMULATION OR REPLAY
ZONE
CONTROL AREA
OWNERS
HELP
DATA MONITORING
Δ TRACKING
HNTGBH-1
COLGAT-2
COLGAT-1
CROKET-U
BLACK-2
BLACK-1
STANIS-1
ELSEGN-3
59 04 09 14 19 24 29 34 39 44 49 54
MM
Δ MW PREDICTION FOR:CROKET-UNIT
13.00 14.00 15.00 16.00 17.00 18.00 19.00
25 20 15 10 5 0 -5 -10 -15 -20
Δ BAD,RAMP ↓
Δ BAD,RAMP ↑
Δ GOOD,RAMP ↓
Δ GOOD,RAMP ↑
SCROLL MONITORING
MONORITING DATA
TRACKING DATA
PRIDICTIVE DATA
SCROLLING DATA
DATE/TIME 29-APR-2003 18:54:00
AUTO REFRESH
SUPPLIER/CA PERFORMANCE FOR AGC
UNIT:CROKET-UNIT
ELECTRIC POWER GROUP, LLC2002
17.55 18.00 18.05 18.10 18.15 18.20 18.25 18.30 18.35 18.40 18.45 18.50
250
200
150
REPLAY
FRAME 361
NORMAL
VIEW ANGLE: 90
N
S
E
W

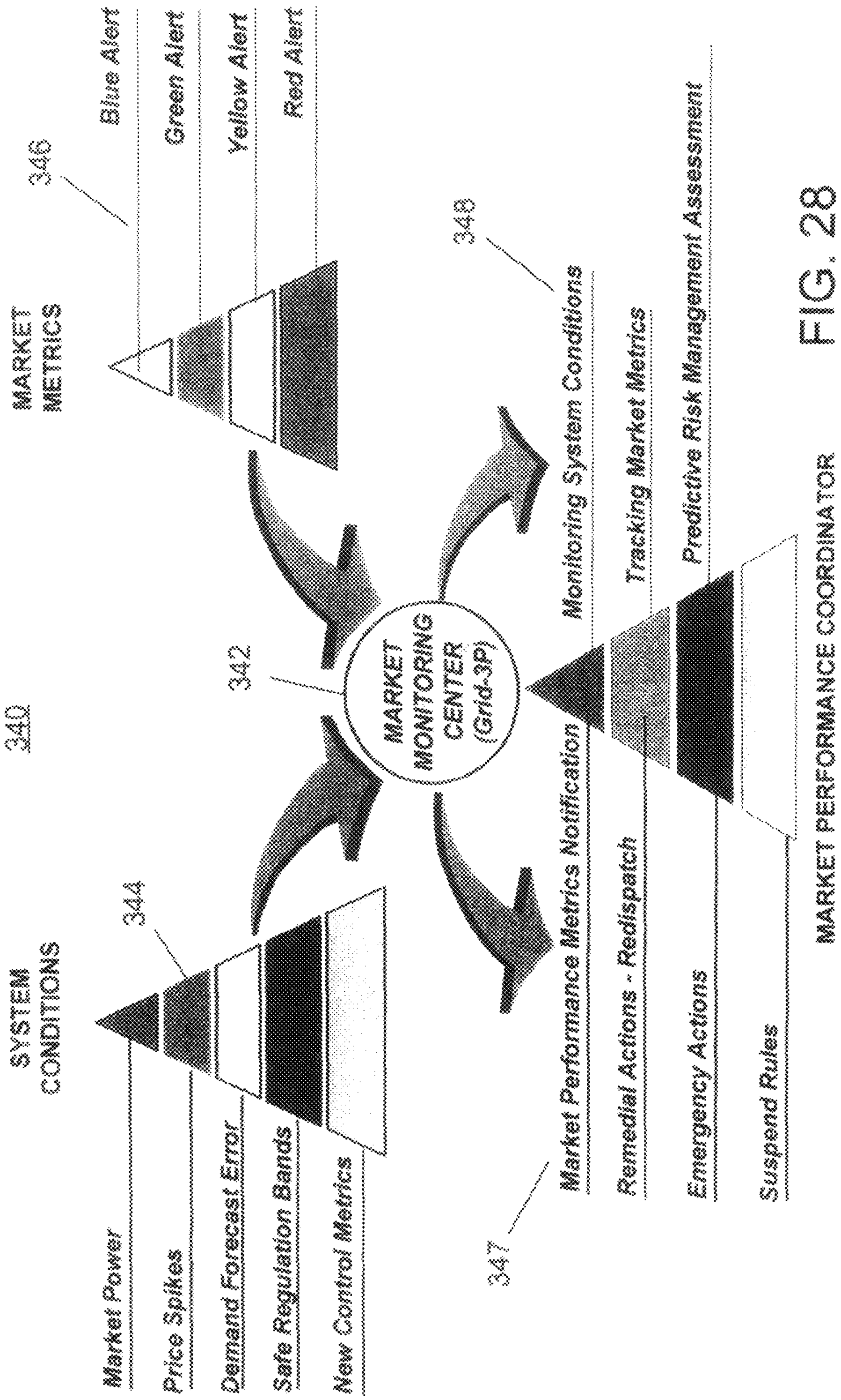

340
SYSTEM CONDITIONS
344
Market Power
Price Spikes
Demand Forecast Error
Safe Regulation Bands
New Control Metrics
MARKET METRICS
346
Blue Alert
Green Alert
Yellow Alert
Red Alert
342
MARKET MONITORING CENTER (Grid-3P)
348
Monitoring System Conditions
Tracking Market Metrics
Predictive Risk Management Assessment
347
Market Performance Metrics Notification
Remedial Actions - Redispatch
Emergency Actions
Suspend Rules
MARKET PERFORMANCE COORDINATOR

FIG. 28


350
352
MONITORING
• PRICE/SPIKES
• IMBALANCE ENERGY
• MARKET POWER INDICES
• DEMAND FORCAST ERROR
354
CORRECTIVE ACTION
• RE-DISPATCH
• PRICE CAPS
• SUSPEND MARKET RULES
• AUTOMATIC MITIGATION
356
HISTORICAL PERFORMANCE TRACKING BY:
• GENERATOR
• CONTROL AREA
• MARKET
• SUPPLIER
358
BID SENSITIVITIES FOR:
• GENERATOR
• PORTFOLIO
• CONTROL AREA
GRID3P
NP 15 SP 15 NORTH SOUTH EAST WEST
DATA COLLECTION
LOGON & PREFERENCES
HELP
MONITORING
TRACKING
SCROLL MONITORING
MONITORING DATA
TRACKING DATA
PRDICTIVE DATA
SCROLLING DATA
CURRENTLY SELECTED:
BACK
REPLAY
VIEW ANGLE: 90

FIG. 29

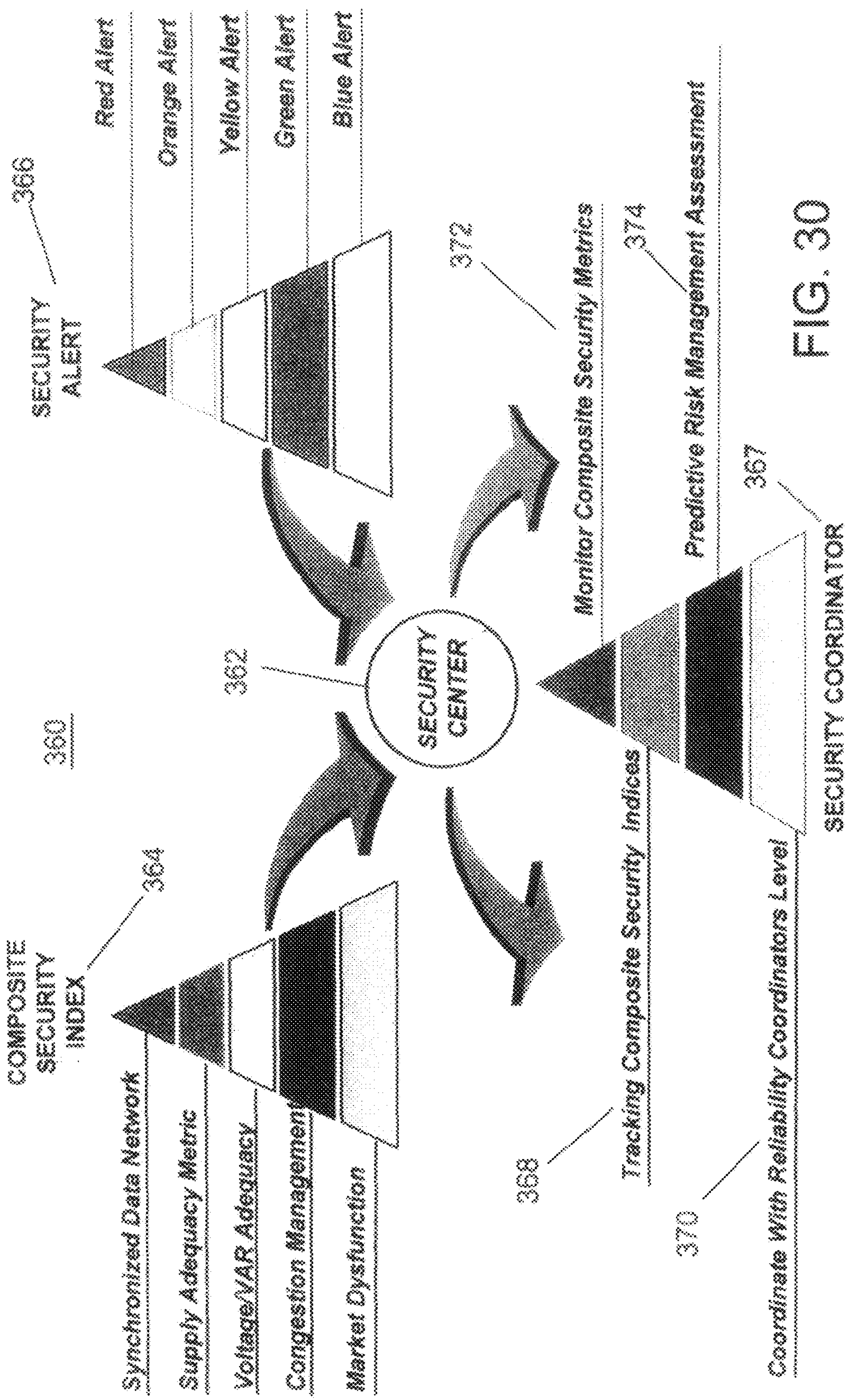
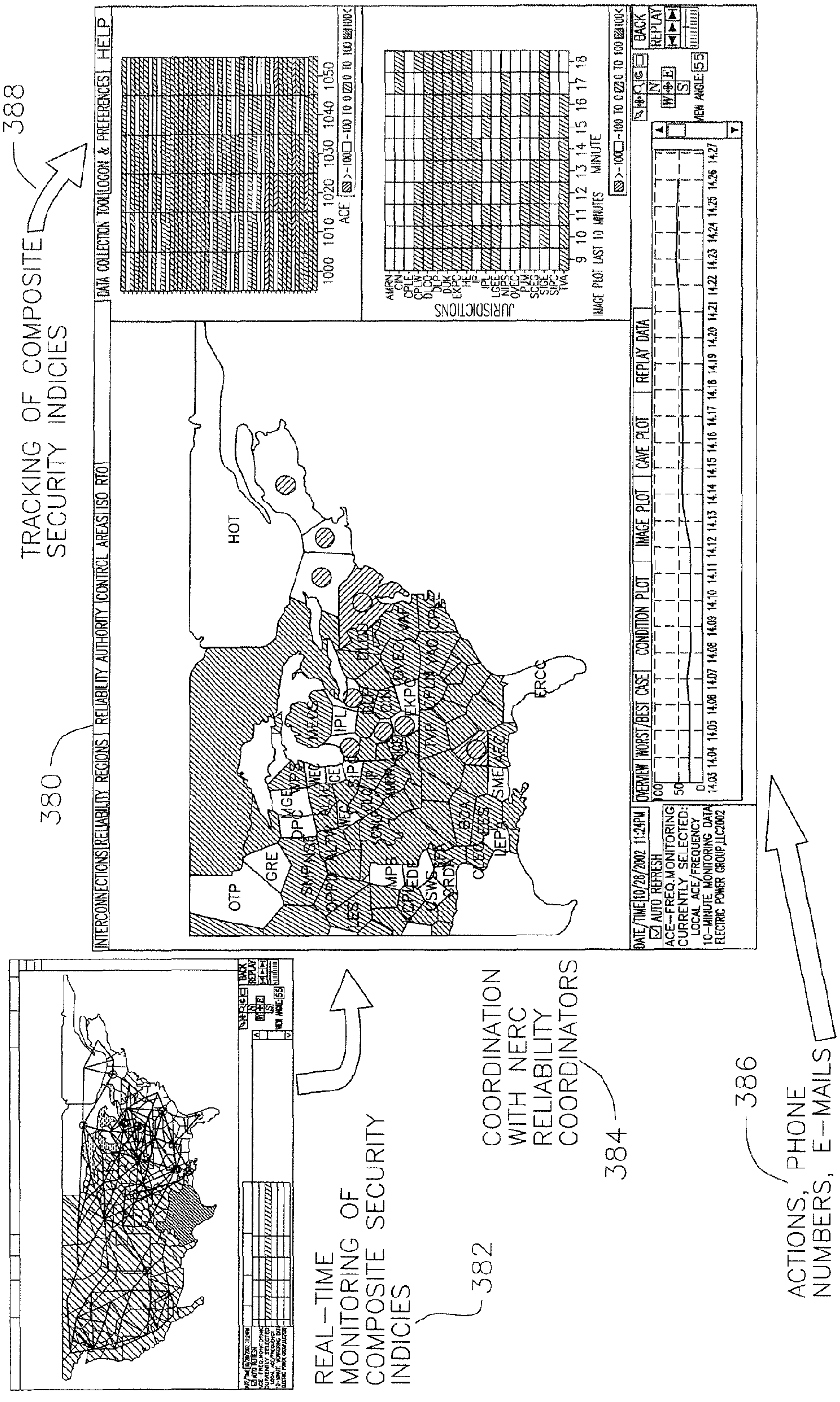
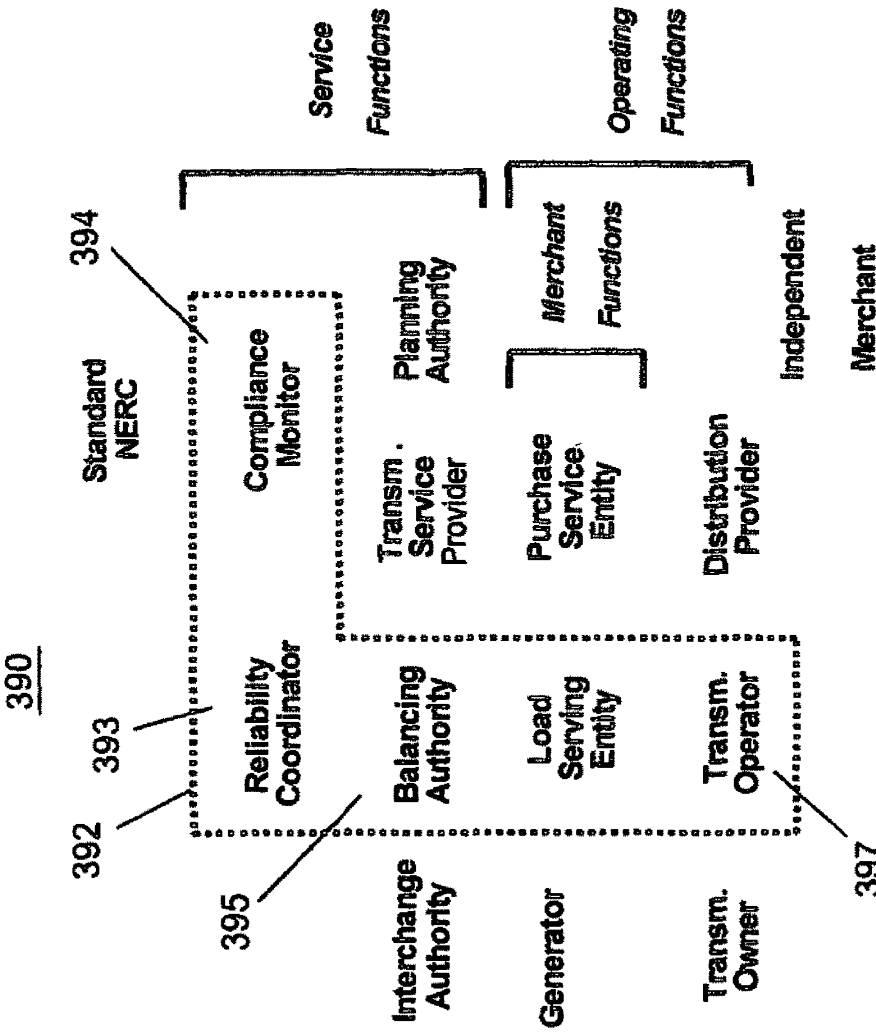

360
362
SECURITY CENTER
364
COMPOSITE SECURITY INDEX
Synchronized Data Network
Supply Adequacy Metric
Voltage/VAR Adequacy
Congestion Management
Market Dysfunction
366
SECURITY ALERT
Red Alert
Orange Alert
Yellow Alert
Green Alert
Blue Alert
367
SECURITY COORDINATOR
368
Tracking Composite Security Indices
370
Coordinate With Reliability Coordinators Level
372
Monitor Composite Security Metrics
374
Predictive Risk Management Assessment

FIG. 30

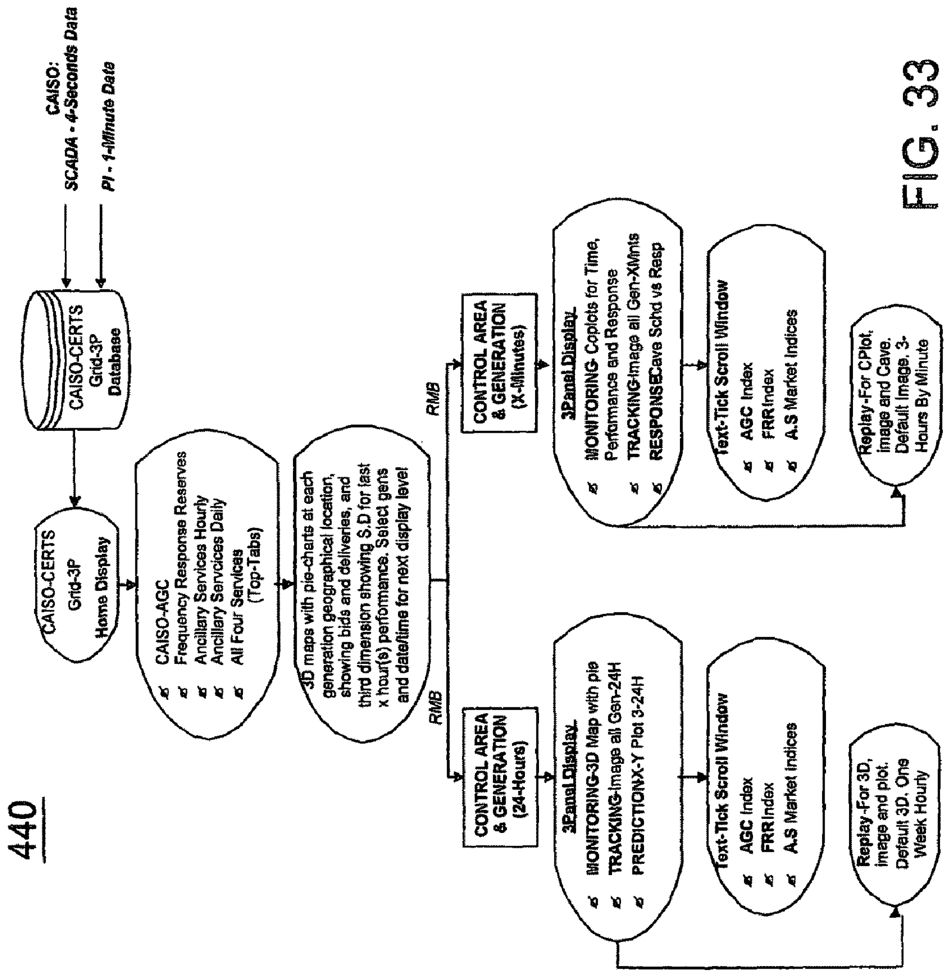
FIG. 31


TRACKING OF COMPOSITE SECURITY INDICIES
388
380
REAL-TIME MONITORING OF COMPOSITE SECURITY INDICIES
382
COORDINATION WITH NERC RELIABILITY COORDINATORS
384
ACTIONS, PHONE NUMBERS, E-MAILS
386
INTERCONNECTIONS
RELIABILITY REGIONS
RELIABILITY AUTHORITY
CONTROL AREAS
ISO RTO
DATA COLLECTION TOOL
LOGON & PREFERENCES
HELP
JURISDICTIONS
IMAGE PLOT LAST 10 MINUTES
MINUTE
ACE
OVERVIEW
WORST/BEST CASE
CONDITION PLOT
IMAGE PLOT
CAVE PLOT
REPLAY DATA
BACK
REPLAY
VIEW ANGLE
DATE/TIME 10/28/2002 11:24PM
AUTO REFRESH
ACE-FREQ. MONITORING
CURRENTLY SELECTED:
LOCAL ACE/FREQUENCY
10-MINUTE MONITORING DATA
ELECTRIC POWER GROUP, LLC2002



390
392
393
394
395
397
Standard NERC
Reliability Coordinator
Compliance Monitor
Interchange Authority
Balancing Authority
Transm. Service Provider
Planning Authority
Service Functions
Generator
Load Serving Entity
Purchase Service Entity
Merchant Functions
Operating Functions
Transm. Owner
Transm. Operator
Distribution Provider
Independent Merchant

FIG. 32



440
CAISO:
SCADA - 4-Seconds Data
PI - 1-Minute Data
CAISO-CERTS Grid-3P Database
CAISO-CERTS Grid-3P Home Display
CAISO-AGC
Frequency Response Reserves
Ancillary Services Hourly
Ancillary Services Daily
All Four Services (Top-Tabs)
3D maps with pie-charts at each generation geographical location, showing bids and deliveries, and third dimension showing S.D for last x hour(s) performance. Select gens and date/time for next display level
RMB
RMB
CONTROL AREA & GENERATION (24-Hours)
CONTROL AREA & GENERATION (X-Minutes)
3Panel Display
MONITORING-3D Map with pie
TRACKING-Image all Gen-24H
PREDICTION-X-Y Plot 3-24H
3Panel Display
MONITORING-Cplots for Time, Performance and Response
TRACKING-Image all Gen-XMnts
RESPONSE-Cave Schd vs Resp
Text-Tick Scroll Window
AGC Index
FRR Index
A.S Market indices
Text-Tick Scroll Window
AGC Index
FRR Index
A.S Market Indices
Replay-For 3D, image and plot. Default 3D. One Week Hourly
Replay-For CPlot, image and Cave. Default Image. 3-Hours By Minute

FIG. 33

FIG.34

450

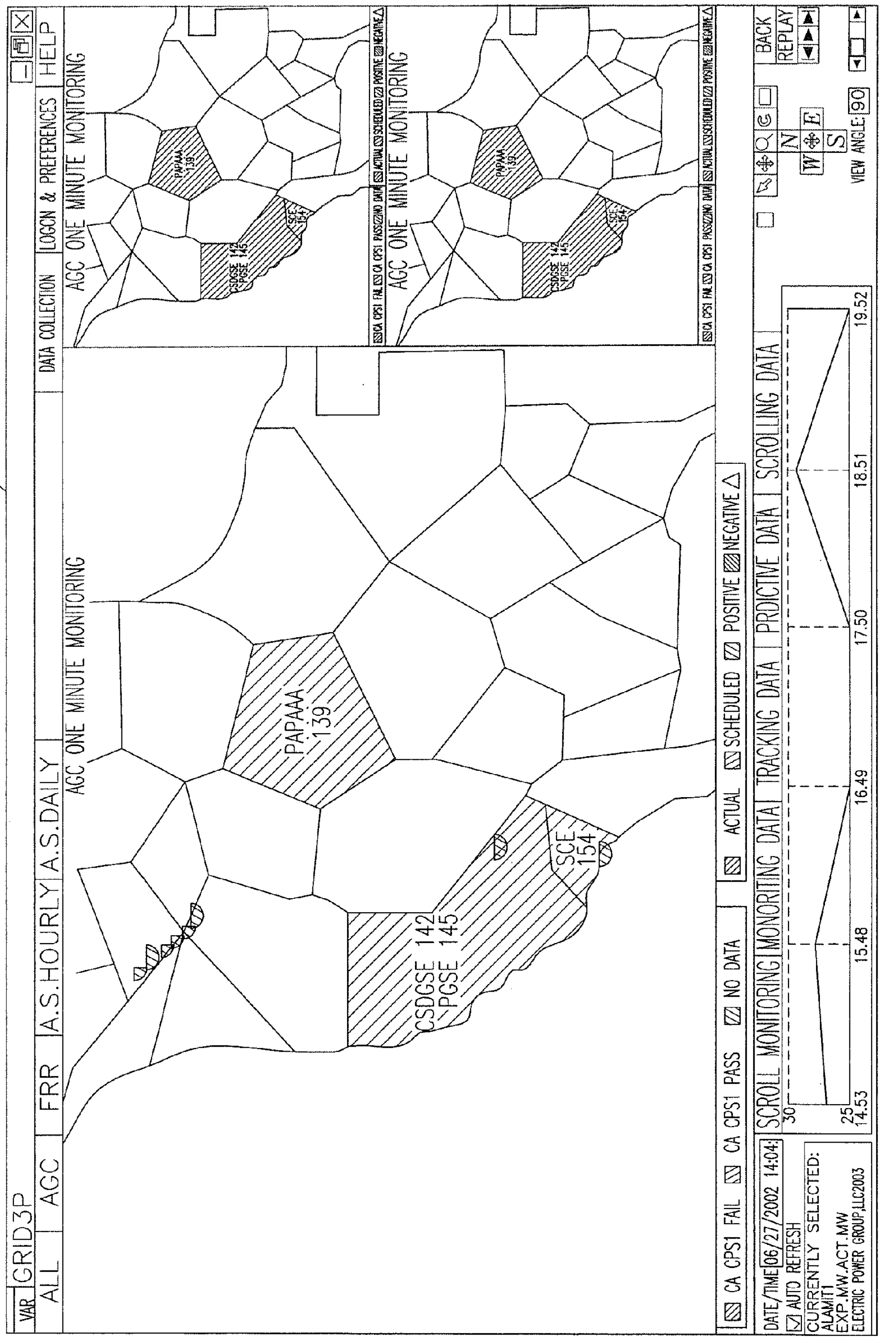

VAR GRID3P
ALL AGC FRR A.S.HOURLY A.S.DAILY
DATA COLLECTION LOGON & PREFERENCES HELP
AGC ONE MINUTE MONITORING
PAPAAA 139
CSDGSE 142
PGSE 145
SCE 154
CA CPS1 FAIL CA CPS1 PASS NO DATA ACTUAL SCHEDULED POSITIVE NEGATIVE
SCROLL MONITORING MONORITING DATA TRACKING DATA PRDICTIVE DATA SCROLLING DATA
DATE/TIME 06/27/2002 14:04
AUTO REFRESH
CURRENTLY SELECTED:
ALAMIT1
EXP.MW.ACT.MW
ELECTRIC POWER GROUP,LLC2003
14.53 15.48 16.49 17.50 18.51 19.52
BACK REPLAY
VIEW ANGLE: 90

FIG. 35

460

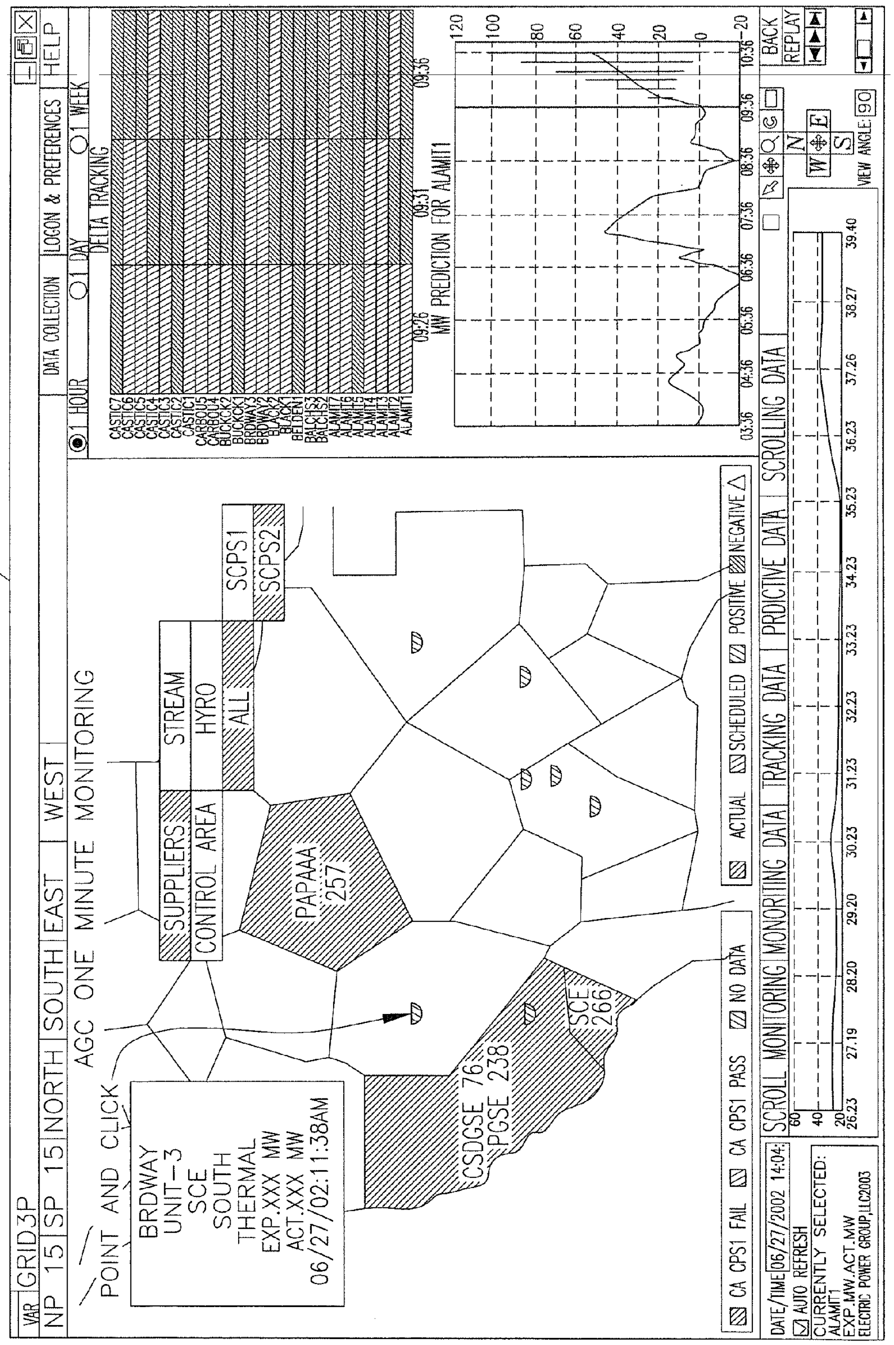

VAR GRID3P
NP 15 SP 15 NORTH SOUTH EAST WEST
LOGON & PREFERENCES
HELP
DATA COLLECTION
AGC ONE MINUTE MONITORING
POINT AND CLICK
BRDWAY
UNIT-3
SCE
SOUTH
THERMAL
EXP.XXX MW
ACT.XXX MW
06/27/02:11:38AM
SUPPLIERS
CONTROL AREA
STREAM
HYRO
ALL
SCPS1
SCPS2
PAPAAA
257
CSDGSE 76
PGSE 238
SCE
266
1 HOUR
1 DAY
1 WEEK
DELTA TRACKING
MW PREDICTION FOR ALAMIT1
CA CPS1 FAIL
CA CPS1 PASS
NO DATA
ACTUAL
SCHEDULED
POSITIVE
NEGATIVE
SCROLL MONITORING
MONORITING DATA
TRACKING DATA
PRDICTIVE DATA
SCROLLING DATA
DATE/TIME 06/27/2002 14:04
AUTO REFRESH
CURRENTLY SELECTED:
ALAMIT1
EXP.MW.ACT.MW
ELECTRIC POWER GROUP,LLC2003
BACK
REPLAY
VIEW ANGLE: 90

FIG. 36

470

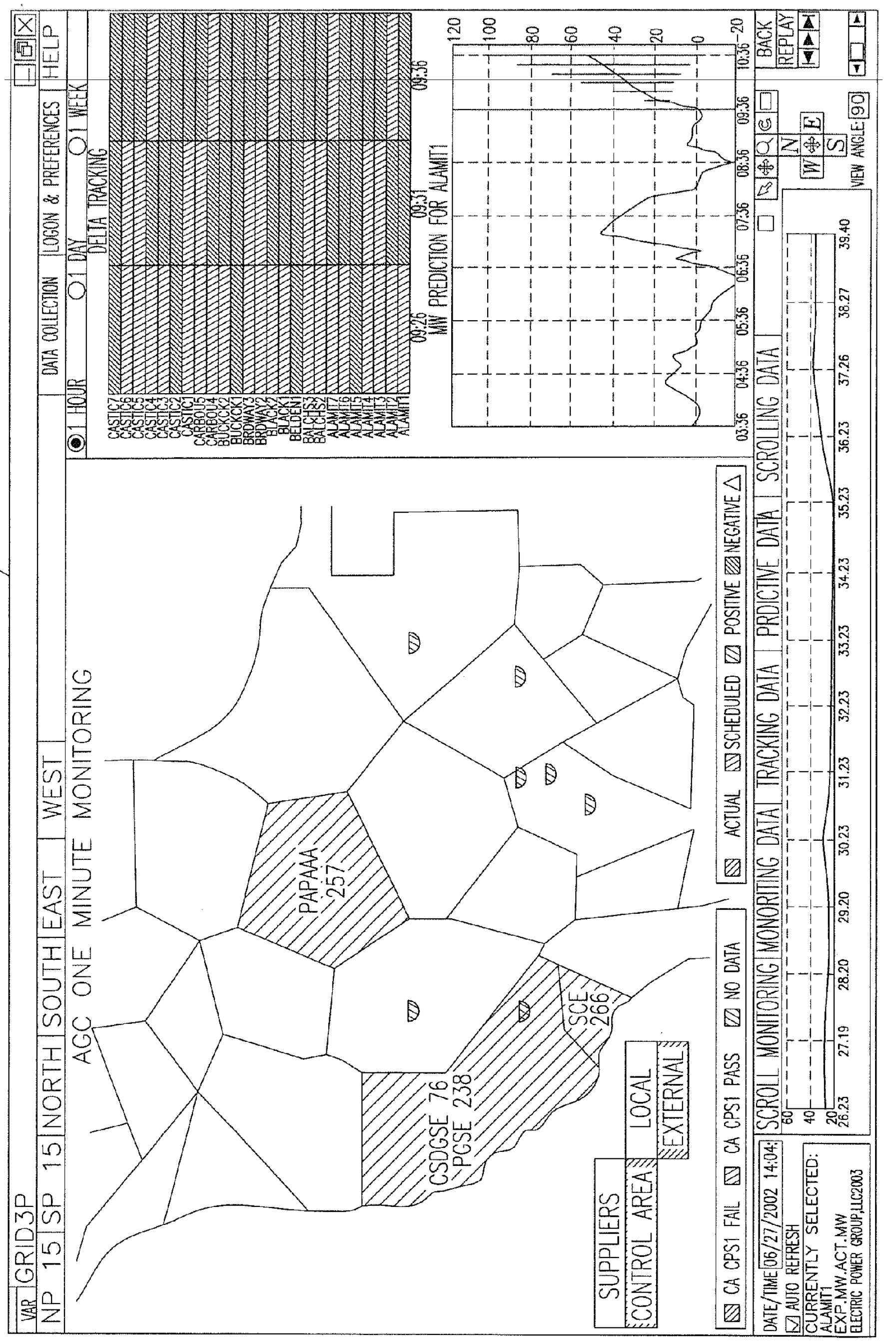
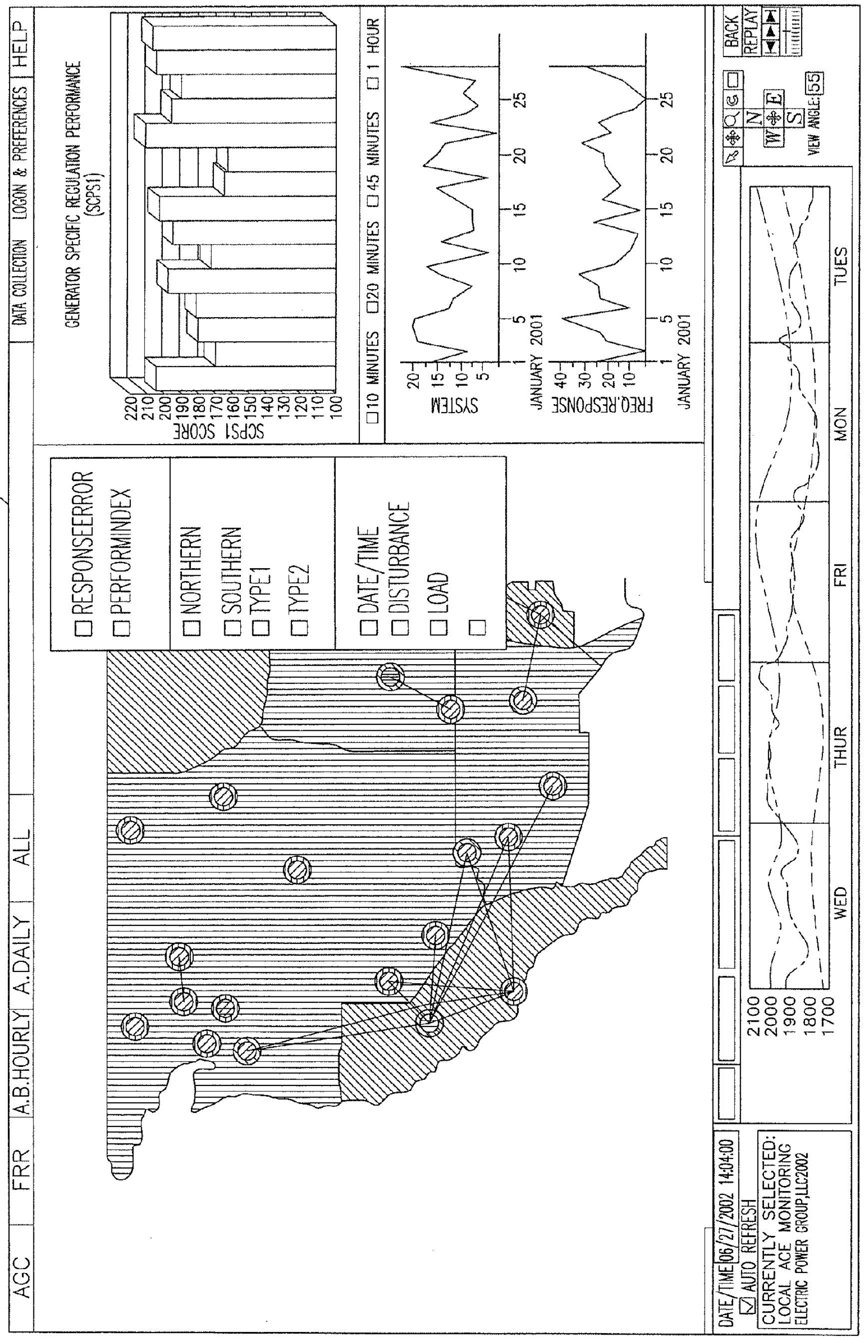

VAR GRID3P
NP 15 SP 15 NORTH SOUTH EAST WEST
AGC ONE MINUTE MONITORING
DATA COLLECTION LOGON & PREFERENCES HELP
1 HOUR 1 DAY 1 WEEK
DELTA TRACKING
PAPAAA 257
CSDGSE 76
PGSE 238
SCE 266
SUPPLIERS
CONTROL AREA
LOCAL
EXTERNAL
CA CPS1 FAIL
CA CPS1 PASS
NO DATA
ACTUAL
SCHEDULED
POSITIVE
NEGATIVE
MW PREDICTION FOR ALAMIT1
SCROLL MONITORING DATA
MONORITING DATA
TRACKING DATA
PRDICTIVE DATA
SCROLLING DATA
DATE/TIME 06/27/2002 14:04
AUTO REFRESH
CURRENTLY SELECTED:
ALAMIT1
EXP.MW.ACT.MW
ELECTRIC POWER GROUP,LLC2003
BACK
REPLAY
VIEW ANGLE: 90

FIG. 37

480



AGC
FRR
A.B.HOURLY
A.DAILY
ALL
DATA COLLECTION
LOGON & PREFERENCES
HELP
GENERATOR SPECIFIC REGULATION PERFORMANCE (SCPS1)
SCPS1 SCORE
10 MINUTES
20 MINUTES
45 MINUTES
1 HOUR
SYSTEM
JANUARY 2001
FREQ.RESPONSE
RESPONSEERROR
PERFORMINDEX
NORTHERN
SOUTHERN
TYPE1
TYPE2
DATE/TIME
DISTURBANCE
LOAD
WED
THUR
FRI
MON
TUES
BACK
REPLAY
VIEW ANGLE: 55
DATE/TIME 06/27/2002 14:04:00
AUTO REFRESH
CURRENTLY SELECTED:
LOCAL ACE MONITORING
ELECTRIC POWER GROUP,LLC2002

490

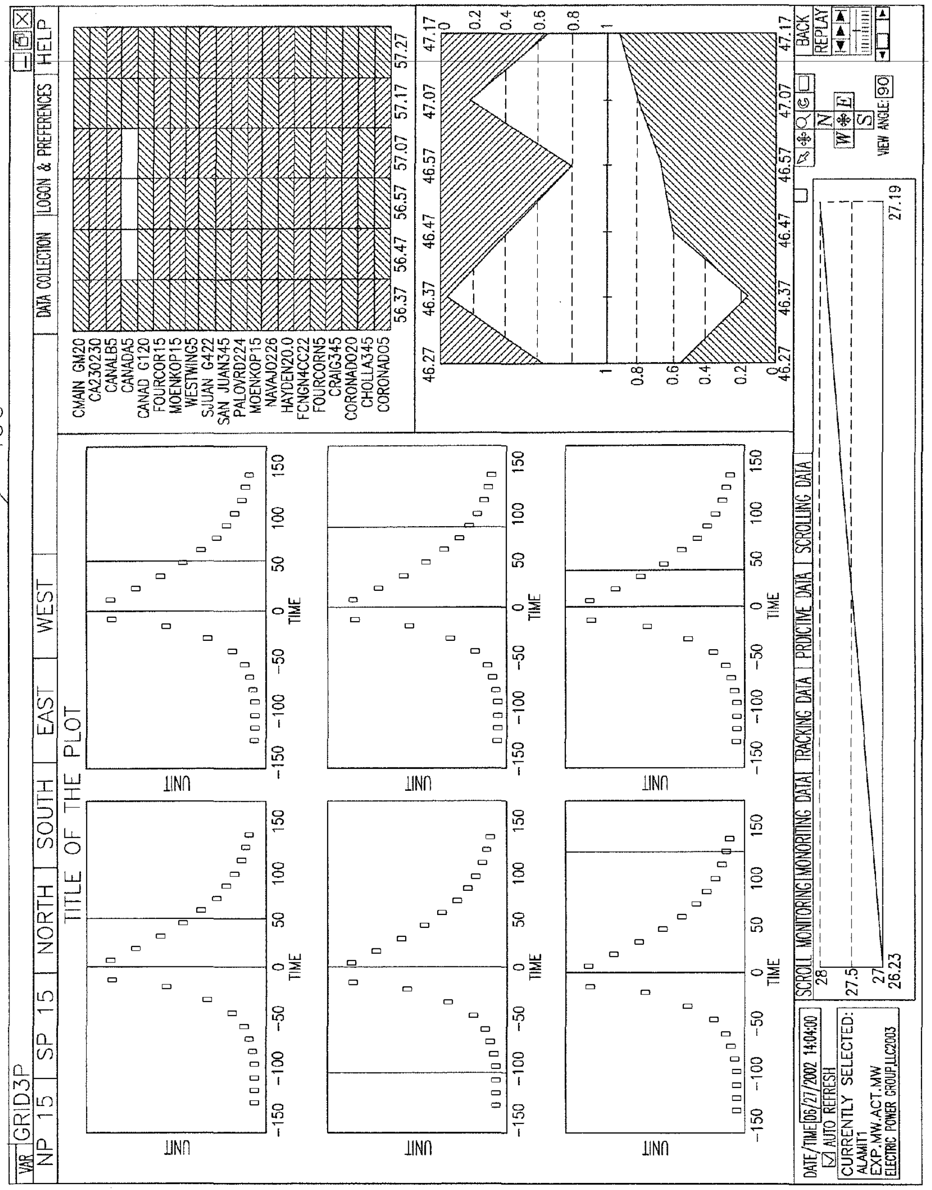

VAR GRID3P
NP 15
SP 15
NORTH
SOUTH
EAST
WEST
DATA COLLECTION
LOGON & PREFERENCES
HELP
TITLE OF THE PLOT
UNIT
TIME
CMAIN GM20
CA230230
CANALB5
CANADA5
CANAD G120
FOURCOR15
MOENKOP15
WESTWING5
SJUAN G422
SAN JUAN345
PALOVRD224
MOENKOP15
NAVAJO226
HAYDEN20.0
FCNGN4CC22
FOURCORN5
CRAIG345
CORONADO20
CHOLLA345
CORONADO5
SCROLL MONITORING
MONITORING DATA
TRACKING DATA
PRDICTIVE DATA
SCROLLING DATA
DATE/TIME 06/27/2002 14:04:00
AUTO REFRESH
CURRENTLY SELECTED:
ALAMIT1
EXP.MW.ACT.MW
ELECTRIC POWER GROUP,LLC2003
BACK
REPLAY
VIEW ANGLE: 90

FIG. 38

WIDE-AREA, REAL-TIME MONITORING AND VISUALIZATION SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. application Ser. No. 10/914,789, filed Aug. 9, 2004 now U.S. Pat. No. 7,233, 843, which claimed the benefit of U.S. Provisional Application Nos. 60/493,526, filed Aug. 8, 2003, and 60/527,099, filed Dec. 3, 2003, the disclosures of which are incorporated fully herein by reference.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

This invention was made partially with government support under Department of Energy Contract # DE-AC03-76SF00098, Subcontract #6508899. The Government has certain rights in this invention.

FIELD OF THE INVENTION

The present invention relates generally to a monitoring and management platform, and more particularly to a real-time performance monitoring and prediction system that has wide applicability to various industries and processes.

BACKGROUND

In various industries, the ability to monitor, track, predict and/or act in real-time is desirable. These industries include electric power, gas pipeline, water systems, transportation, chemicals and processes, infrastructure protection, security monitoring and others.

By way of example, in the electric power industry, power is typically supplied to customers in a four stage process of generation, transmission, distribution and end use. FIG. **1**A illustrates a typical process of generation, transmission and distribution of electricity. As illustrated in FIG. **1**A, the electricity is generated competitively by a number of power plants. The electricity is then transmitted through a number of transmission lines that are regulated by the Federal Energy Regulatory Commission (FERC). These transmission lines, which may be located in different states, are typically owned by the utility or transmission companies, and controlled by regional Independent System Operators (ISOs), Regional Transmission Organizations (RTOs) or utility companies that may be private or public. The generation and transmission of electricity are usually managed by regional entities that monitor the grid operations, market operations, security and other aspects of the electric power system.

The transmitted electricity is typically distributed through state or locally regulated distribution companies. The transmission and distribution systems utilize a number of devices for management and control of the electric system, including dynamic voltage support, remedial action schemes, capacitors, storage and flow control devices. The electricity is distributed to the customers as the end users, or consumers of electricity. Some of the customers may also have micro-grids of their own. The demand placed by these customers also needs to be managed.

Due to the enormous task at hand, there are a number of organizations responsible for overseeing these power generation, transmission and distribution activities. For example, there are over 3,000 utilities, thousands of generators, 22 Reliability Coordinators, and 153 Control Areas (CAs) in the

United States for monitoring and control of generation, transmission and distribution of electricity. While all these different entities at various different levels are involved in generation, transmission and distribution of electricity as well as monitoring and control in a power grid, there is no single integrated system that can be used to monitor and manage the electric power grid in real-time across all of the different elements of the power system. For example, there is no information management system for the power grid, which is integrated across multiple business systems, companies and Control Areas to manage the security, timeliness, accuracy or accessibility of information for grid operations, reliability, market operations and system security. Analogous issues may be apparent in other industries.

SUMMARY

In an exemplary embodiment according to the present invention, a real-time performance monitoring, management and prediction platform is provided. Systems based on the platform may be used to manage processes in various industries, based on current monitoring tools as well as tools that are under development, for example, in smart, switchable networks. Systems based on the platform preferably include visualization features that enable managers and operators in various industries to: measure key system operating and market metrics; monitor and graphically represent system performance, including proximity to potential system faults; track, identify and save data on abnormal operating patterns; and predict system response in near real-time by means of simulations and predictive analysis.

In one exemplary application of the present invention, a power grid monitoring and management system is provided. The power grid monitoring and management system includes a technology platform for real-time performance monitoring application for the electric power grid. The power grid monitoring and management system in one exemplary embodiment may also be referred to as a Grid Real-Time Performance Monitoring and Prediction Platform (Grip-3PTM). The Grid-3P platform is designed to enable monitoring of a range of electric grid parameters, including metrics for reliability, markets, generation, transmission, operation, and security. The visualization features enable display of information geographically and graphically; in real time; and enables operators to define display levels local or wide area, control area, interconnection or other user defined manner. This technology is being used to develop and implement real-time performance monitoring applications at Reliability Coordinator and Independent System Operator (ISO) locations, including the following applications: Area Control Error (ACE)-Frequency Real-Time Monitoring System; Control Area and Supplier's Performance for Automatic Generation Control and Frequency Response Services System; VAR-Voltage Management and Monitoring System; and Monitoring Applications based on Synchronized Phasor Measurements.

Examples of electric grid system components and metrics that could be monitored include electric interconnections, generators, voltage levels, frequency, market prices, congestion, market power metrics, demand forecasts, and other system components and metrics.

Another feature of the Grid-3P platform is the concept of multi-panel displays that allow: real-time monitoring of key metrics; display of history and performance tracking of key metrics; performing sensitivity evaluations and assessments of key metrics under alternative scenarios, and developing predictions or near term forecasts of performance; and initi-

ating actions, such as providing e-mail notification for alerting operators about abnormal conditions and the need to take action.

The power grid monitoring and management system may operate in a web environment, client-server, dedicated server, and/or secure proprietary network. In addition, the power grid monitoring and management system may allow interactive historical data collection and to present the collected data in tabular and/or specialized data-visuals. Further, the power grid monitoring and management system may be used to create interactive data reports from grid performance historical data saved in data-servers.

In an exemplary embodiment according to the present invention, a real-time performance monitoring system monitors an electric power grid having a plurality of grid portions, each said grid portion corresponding to one of a plurality of control areas. A monitor computer monitors at least one of reliability metrics, generation metrics, transmission metrics, suppliers metrics, grid infrastructure security metrics, and markets metrics for the electric power grid. A database stores the metrics being monitored by the monitor computer, and at least one display computer has a monitor for displaying a visualization of the metrics being monitored by the monitor computer. Said at least one display computer in one said control area enables an operator to monitor a said grid portion corresponding to a different said control area.

In another exemplary embodiment according to the present invention, a method of monitoring a performance of an electric power grid in substantially real-time is provided. The electric power grid has a plurality of grid portions, each said grid portion corresponding to one of a plurality of control areas. A monitor computer is used to monitor at least one of reliability metrics, generation metrics, transmission metrics, suppliers metrics, grid infrastructure security metrics, and markets metrics for the electric power grid. The metrics being monitored by the monitor computer is stored in a database, and a visualization of the metrics being monitored by the monitor computer is displayed on a monitor of at least one display computer. Said at least one display computer in one said control area enables an operator to monitor a said grid portion corresponding to a different said control area.

These and other aspects of the invention will be more readily comprehended in view of the discussion herein and accompanying drawings, in which like reference numerals designate like elements.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A illustrates a typical process of generation, transmission and distribution of electricity;

FIG. **1**B illustrates a process of generation, transmission and distribution of electricity, and a set of exemplary information management requirements according to the present invention;

FIG. **2**A is a block diagram that illustrates an exemplary performance management strategy according to the present invention;

FIG. **2**B illustrates a process of controlling generation, transmission and distribution of electricity with an integration of real time wide area monitoring for reliability management;

FIG. **2**C illustrates an infrastructure for a wide area reliability monitoring center (WARMC) of FIG. **2**B;

FIG. **3** is a block diagram that illustrates an exemplary performance management process according to the present invention;

FIG. **4** is a block diagram that illustrates an exemplary multi-layered platform for performance monitoring and management according to the present invention;

FIG. **5** is a block diagram that illustrates the integration into power generation, transmission and distribution of the power grid monitoring and management system in an exemplary embodiment according to the present invention;

FIG. **6** illustrates a power grid monitoring and management system of FIG. **5** and includes the major reliability applications for real-time reliability monitoring for NERC Reliability Coordinators and Control Area Dispatchers;

FIG. **7** illustrates an application of the power grid monitoring and management system for utilization by RTOs to monitor markets, operations, security, and other functions;

FIG. **8** illustrates an application of the power grid monitoring and management system in an exemplary embodiment according to the present invention;

FIG. **9** is a local area network (LAN) based hardware and software architecture for the power grid monitoring and management system in an exemplary embodiment according to the present invention;

FIG. **10** is a web-based hardware and software architecture for the power grid monitoring and management system in another exemplary embodiment according to the present invention;

FIG. **11** illustrates the architecture of an ACE-Frequency real-time monitoring application using the power grid monitoring and management system in an exemplary embodiment according to the present invention;

FIG. **12** illustrates five major functional components of the NERC ACE-Frequency real-time monitoring system in an exemplary embodiment according to the present invention;

FIG. **13** illustrates reliability functional levels and visualization hierarchy in an exemplary embodiment according to the present invention;

FIG. **14** illustrates an integrated visualization model in an exemplary embodiment according to the present invention;

FIG. **15** illustrates an ACE-Frequency real-time monitoring architecture of the power grid monitoring and management system in an exemplary embodiment according to the present invention;

FIG. **16** is a screen shot that illustrates a multiple view architecture of a display of the power grid monitoring and management system in an exemplary embodiment according to the present invention;

FIG. **17** is screen shot of a Cave diagram that represents a Frequency/ACE diagram in an exemplary embodiment according to the present invention;

FIG. **18** is a screen shot of a default display for a Reliability Authority in an exemplary embodiment according to the present invention;

FIG. **19** is a screen shot of an Interconnect-Epsilon map in a three-panel display in an exemplary embodiment according to the present invention;

FIG. **20** is a screen shot of a local view for a Control Area map in an exemplary embodiment according to the present invention;

FIG. **21** is a screen shot of a current Control Area map for a selected Control Area in an exemplary embodiment according to the present invention;

FIG. **22** is screen shot of a CPS map in an exemplary embodiment according to the present invention;

FIG. **23** is a screen shot of a three-panel view in an exemplary embodiment according to the present invention;

FIG. **24** is a screen shot of a data collection tool in an exemplary embodiment according to the present invention;

FIG. **25** is a screen shot of charts generated using the data collected using the data collection tool of FIG. **24**.

FIG. **26** illustrates utilization of NERC ACE-Frequency monitoring in an exemplary embodiment according to the present invention;

FIG. **27** illustrates a screen shot of a supplier-Control Area performance for AGC and frequency response application in an exemplary embodiment according to the present invention;

FIG. **28** illustrates a market monitoring system in the power grid monitoring and management system in an exemplary embodiment according to the present invention;

FIG. **29** illustrates a screen shot of a market monitoring application in an exemplary embodiment according to the present invention;

FIG. **30** illustrates a security center monitoring system in an exemplary embodiment according to the present invention;

FIG. **31** illustrates a screen shot of a real-time security monitoring application of the power grid monitoring and management system in an exemplary embodiment according to the present invention;

FIG. **32** is a block diagram of a NERC reliability functional model in an exemplary embodiment according to the present invention;

FIG. **33** illustrates a Control Area and suppliers performance monitoring and prediction platform for AGC, FRR and regulation A.S. in an exemplary embodiment according to the present invention;

FIG. **34** is a screen shot of a panel view for control area and suppliers performance for, AGC, FRR and A.S. in an exemplary embodiment according to the present invention;

FIG. **35** is a screen shot of a panel view for Control Area and generator response to AGC in an exemplary embodiment according to the present invention;

FIG. **36** is a screen shot for a panel view for Control Area and generators response to frequency response in an exemplary embodiment according to the present invention;

FIG. **37** is a screen shot for a panel view for Control Area and generators response to regulation A.S. in an exemplary embodiment according to the present invention; and

FIG. **38** is a screen shot of a common view for performance of AGC, FRR and X-minutes ancillary services regulation (default 10 minutes) in an exemplary embodiment according to the present invention.

DETAILED DESCRIPTION

Referring to FIG. **1**B, a set of exemplary information management requirements for the present invention may include: integration across multiple business system, companies and CAs; and information security, timeliness, accuracy, and accessibility.

Referring to FIG. **2**A, an exemplary performance management strategy according to the present invention contemplates identification of key metrics **1**, monitoring **2**, analysis **3** and assessment **4**. Utilizing the platform and system described herein, the strategy may be beneficially employed for a wide variety of industries and processes, including without limitation, electric power, gas pipeline, water systems, transportation, chemicals and processes, infrastructure protection, security monitoring and others.

According to an exemplary embodiment of the present invention, a wide area reliability monitoring center (WARMC) provides a visibility to system conditions across control area boundaries, improves reliability management capability, and/or prevents future blackouts. The WARMC provides Reliability Coordinator and Control Area operators with a wide area perspective of grid operations real-time, beyond its immediate area of responsibility. The WARMC may additionally have other functions and applications including new functions and applications to be developed, and may serve as a center that supports grid reliability for an entire Interconnection (e.g., Eastern Interconnection (EI)), for example.

In recent years, the functional disaggregation of electric utilities has resulted in gaps in the overall grid reliability management in terms of who (Control Areas, Reliability Coordinators, ISO/RTOs) has visibility of key system parameters with apparently no one having the full picture. By way of example, blackouts, such as the Aug. 14, 2003 blackout in the United States and Canada, may have been caused by a lack of situational awareness caused by inadequate reliability tools and backup capabilities. Further, deficiencies in control area and reliability coordinator capabilities to perform assigned reliability functions may also have led to blackouts.

During the blackouts, the operators may have been unaware of the vulnerability of the system to the next contingency. The reasons for this may include one or more of inaccurate modeling for simulation, no visibility of the loss of key transmission elements, no operator monitoring of stability measures (e.g., reactive reserve margin, power transfer angle), and no reassessment of system conditions following the loss of an element and readjustment of safe limits. The wide area real time monitoring for reliability management of the present invention is adapted to the changing industry structure and helps to reduce or prevent blackouts.

The wide area reliability monitoring functions of the present invention may be integrated with existing operations and provide system operators and Reliability Coordinators with tools for monitoring not only their own Control Areas but also adjacent Control Areas and the Interconnection. The integration of the real time wide area monitoring for reliability management with existing control, communications, and monitoring infrastructure is shown in FIG. **2**B, for example.

As shown in FIG. **2**B, operators currently have access to databases or platforms and perform control and monitoring functions at three levels: 1) Level 1—local power plant controls using plant data to control local generation of power; 2) Level 2—SCADA (regional control center) using generation, transmission and substations data to control regional and local substations, which involves controlling local load-generation balance-AGC and local grid switching in real-time; and 3) Level 3—EMS for Control Area operations including use of state estimation, grid security analysis and security constrained dispatch, using grid voltage and interconnection frequency-ACE data.

The WARMC according to an exemplary embodiment of the present invention introduces a new Level 4, which utilizes existing SCADA data as well as time synchronized data from phasors or other sources and/or other new data sources for wide area monitoring. As shown in FIG. **2**B, the WARMC provides one or more of the following applications: 1) Wide-Area Load-Generation Balance-ACE-Frequency real-time monitoring; 2) Wide-Area Grid Dynamics and Reliability monitoring-RTDMS; 3) real time operations management information; and 4) state estimation using phasors. The WARMC may have one or more of other monitoring, management information reporting, state estimation, and controls applications.

The WARMC provides a wide area monitoring and reliability management capability that extends across control area boundaries. The WARMC may include one or more of monitoring applications, connectivity with other Intercon-

nection entities, improved phasor and PDC hardware, and secure and redundant communication networks for data exchange. The WARMC may enable RTOs, Independent Transmission Owners (TOs), North American Electrical Reliability Council (NERC), other Interconnection stake holders, and/or the like to monitor key reliability metrics impacting their respective areas and provide the capability to monitor and manage an entire Interconnection grid (e.g., Eastern Interconnection grid).

By way of example, the WARMC may provide one or more of the following functions or capabilities: 1) wide area system visibility; 2) data connectivity to key RTOs and reliability management organizations; 3) time synchronized data in real time; 4) monitoring of key grid reliability metrics for an Interconnection (e.g., Eastern Interconnection); 5) real time performance monitoring and reporting; 6) enhanced state estimation; 7) fast simulation and modeling; and 7) smart grid with automated controls.

The WARMC may be fully automated, such that it will compile critical high speed data, process it, provide Interconnection (e.g., EI) reliability authorities with reliability information on the health of the Interconnection and, as required, may enable/disable remedial actions schemes (RAS) and may re-configure the grid. The WARMC may be linked through secure, reliable and redundant communications to key RTOs, transmission owners, utilities, and control area operators. The conceptual framework for an WARMC infrastructure is shown in FIG. **2**C. As can be seen in FIG. **2**C, the WARMC **2'** is coupled via a wide area network to a number of RTOs **1**-*n*, one or more super computers and a number of TOs **1**-*n*.

The WARMC should have access to critical real-time and historical operating data from all regions of an Interconnection (e.g., EI) to perform one or more of real time monitoring, post disturbance assessments, analyses for future enhancements and modeling to support a smart grid with automatic controls.

By way of example, the WARMC may have the necessary infrastructure, support systems and data to provide meaningful information for TOs, RTOs, and Reliability Coordinators to effectively perform one or more of the following: 1) validate the next-days operating plan and ensure the bulk power system can be operated reliably in anticipated normal and contingency conditions; 2) perform wide area monitoring, tracking and management of real-time grid operations; 3) anticipate and respond to changing conditions and flows; and 4) simulate “what if” scenarios.

The WARMC may also have capabilities to perform post disturbance assessment functions including one or more of: 1) evaluating compliance with NERC/Reliability Regional Standards; 2) Providing feedback to the pre-planning (day-ahead) process; 3) and validating model representation of expected grid performance. The WARMC may also define enhancements to the grid by, for example, assessing constraints, bottlenecks and vulnerabilities that will have a negative impact on grid reliability.

Referring now to FIG. **3**, the identification and use of key metrics **1** involves the evaluation and development of standards that may be quantified and measured. Metrics exist for a particular industry and different areas of a particular industry. For example, there may be metrics relating to reliability and others relating to markets, in which the metrics for each subcategory may overlap. Monitoring **2** contemplates the use of tools, whether they exist now or become available in the future, for tracking actual performance in real-time with a goal, among others, of looking for early warning signs. Analysis **3** contemplates converting archived monitoring information into meaningful information. Such data includes without limitation, risk analysis, grid data, depending on the particular industry or process being monitored, market data, historical data, and key reliability indicators. Assessment **4** contemplates the determination of impacts on reliability, markets, efficiency and asset utilization. Examples, which may change depending on the particular industry or process being assessed, include risk assessment, grid reliability and market efficiency. The desired assessment may modify the parameters or metrics that are monitored to achieve the desired results.

In one exemplary application of the present invention, the Grid-3P system, based upon a real-time performance and prediction platform for power grid monitoring and management, includes monitoring of generation/demand, grid data and markets as more particularly set forth herein. By way of example, the WARMC discussed above may be based on the Grid-3P system.

The reliability applications may include one or more of real-time monitoring of voltage/volt-ampere reactive (VAR), Area Control Error (ACE)/Frequency, Area Interchange Error (AIE)/Schedules, and/or other grid attributes and performance metrics. The generation applications may include suppliers and Control Area responses to Automatic Generation Control (AGC), frequency response and ancillary services, ramping response, and/or other metrics. The grid infrastructure security application may include one or more of system vulnerability, exposure (in terms of population, cities, etc.) and/or other metrics. Market applications may include one or more of generation market power, price spikes and/or other metrics.

In another exemplary embodiment according to the present invention, the power grid monitoring and management system enables one or more of real-time monitoring, historical tracking, prediction (near real-time forecasting up to 6-hours or what if sensitivity analysis), and actions (notification, system re-dispatch, mitigation measures, etc.) In other embodiments, the forecasting may be performed for more than six (6) hours.

In still another exemplary embodiment according to the present invention, the power grid monitoring and management system provides displays that utilize data and information that are user-defined and may or may not be algorithmically correlated with other displays.

In a further exemplary embodiment according to the present invention, data monitoring may be in real-time or near real-time for monitoring purposes. For example, real-time may be 1-4 seconds snapshot or up to 5 to 10 minute snap shots.

In yet further exemplary embodiment according to the present invention, the power grid monitoring and management system may be utilized to create a standalone monitoring system or be integrated with Security Control and Data Acquisition (SCADA), Energy Management System (EMS), PMUs-PDCs (phasor measurement units-phasor data concentrators) or other control power systems. The SCADA is a system of remote control and telemetry used to monitor and control transmission systems. In other words, the power grid monitoring and management system utilizes data from or is integrated with at least one of SCADA, EMS, PMUs-PDCs and another control power system.

In a still further exemplary embodiment according to the present invention, the power grid monitoring and management system may be used with standard monitoring and control applications and/or end-user defined customer applications.

Referring to FIG. **4**, the platform incorporates a multi-layered approach to performance monitoring and manage-

ment. Layer **1** (**5**), the data layer, incorporates conventional relational databases with time series capability (for real-time monitoring and synchronization), a data archival system and/or information management with data mining capabilities. Further, layer **1** includes web-based data communications, COM+ databases and data conversion APIs. One purpose of Layer **1** is to read data from conventional databases that gather the data in real-time, and to communicate the data in real-time.

Layer **2** (**6**), which uses analytical algorithms for massaging the data accumulated in the databases of layer **1**, includes two sublayers (**6***a* and **6***b*), one focusing on optimization, forecasting, statistics and probabilistic technologies, and other on real-time performance monitoring. Within layer **2***a* (**6***a*), the platform includes tools and algorithms for linear and non-linear optimizing, self-organize maps and generic algorithms, forecasting, probabilistic analysis and risk assessment, multivariate statistical assessment, performance metrics definition and assessment, and other analytical technologies that may become available. Within layer **2***b* (**6***b*), the system includes real-time ACE-frequency monitoring, real-time suppliers control area performance for AGC and FR, voltage VAR management, dynamics monitoring using phasor measurements and other applications that may become available.

Dynamic monitoring using phasor analysis is particularly important in systems where monitoring data at subtransient levels may be useful. By way of example, existing power systems have dynamic behavior on the order of milliseconds. Traditional sampling, however, occurred at 4 second intervals. New monitoring techniques enable sampling up to 20-30 times per seconds or more. The present system, using dynamic phasor analysis, is capable of analyzing data gathered at subtransient intervals, synchronizing the data to other system parameters based on the time series capability of layer **1**, and presenting the data for visualization in an organized and logical manner in layer **3**.

Deployment of phasor technology over wide areas is useful for supporting reliable region-wide and inter-regional transfers of electricity without facing transient reliability conditions. An objective of real time dynamics performance monitoring using phasors is to provide grid operators with phasor data in real-time so that they can obtain a more accurate picture of the actual health of the grid. The information allows them to verify that they are operating within the transient boundaries of safe operation, as determined by off-line planning studies, as well as whether the operating guidelines provided by these studies remains valid. Such real-time data provided by phasor or other real time monitoring technologies also supports creation of an automatic, switchable grid that can sense and respond automatically to warning signs of grid emergencies.

Layer **3** (**7**) uses a novel visualization system that includes a multi-layer view for geo-graphic, wide and local areas. Such a system that allows local or wide area visualization provides significant benefits for understanding the effect of national or neighboring areas on local areas or interest, such as local utilities. In yet another exemplary embodiment according to the present invention, the power grid monitoring and management system is flexible to include one or more dynamic geographic displays and several data or text panels in one or more windows for monitoring, tracking, prediction, and actions or mitigations. Further, by synchronizing data from various sources and presenting it as such, the system enables the user to visualize a wide array of phenomena that may have an impact at a given time on the area or process of interest. The system further provides auto-onelines for tracing the path of electricity, water or other resources through the system. These diagrams allow the user to visualize potential sources of faults or other aspects of the system that may lead to system faults, and to take appropriate action prior to such a fault.

In an exemplary application of the present invention, new methods, tools and technologies are provided to protect and enhance the reliability of the U.S. electric power system by providing a real-time performance monitoring platform. The power grid monitoring and management system of the present invention, for example, includes a platform for performing real-time monitoring of frequency of electricity, customer usage ("load") and/or the amount of power being generated ("generation"). What may also be monitored is the difference between load and generation, and its effect on the frequency of the system.

In the exemplary embodiment, the system includes a series of modular, but integrated, computer-based, real-time data-to-information engines and graphic-geographic visualization tools that have served as a platform to develop reliability applications to assist operating authorities, business entities or companies, e.g., Independent System Operators (ISOs), Regional Transmission Organizations (RTOs), Reliability Coordinators and Control Area Dispatchers in their management of grid reliability, which may use different business systems. For North American Electric Reliability Council (NERC), these applications include the ACE-Frequency and AIE real-time monitoring systems.

The ACE may be defined as an instantaneous difference between net actual and scheduled interchange (i.e., energy transfers that cross control area boundaries), taking into account the effects of frequency bias including a correction for meter error. An AIE survey may be used to determine the Control Areas' interchange error(s) due to equipment failures or improper scheduling operations or improper AGC performance, where AGC may refer to equipment that automatically adjusts a Control Area's generation from a central location to maintain its interchange schedule plus frequency bias. The ACE and AIE monitoring systems together may be referred to as a Compliance Monitoring System (CMS). The CMS may also include one or more other components.

The ACE-Frequency and AIE real-time monitoring system applications enable NERC Reliability Coordinators to monitor ACE-Frequency performance and compliance with performance operational guides within their jurisdictions, and also allow NERC staff and subcommittees to analyze and assess control data to improve reliability tracking and performance. The ACE-Frequency real-time monitoring system, for example, translates raw operational control data into meaningful operations performance information for end users. Should an abnormal interconnection frequency occur, a real-time interconnection abnormal frequency notification (AFN) may be automatically issued via e-mail and/or beepers describing the date, time and magnitude of the frequency abnormality to specific operational authorities, NERC Resource Subcommittee members and NERC Staff.

The notification recipients using the ACE-Frequency monitoring system functionality can quickly assess the abnormality's root cause by drilling down from wide-area to local-area visualization displays that include appropriate information and analysis graphs to easily identify and assess those Control Area(s) out of compliance and potential originators of the notified interconnection frequency abnormality. A Control Area may be defined as an electrical system bounded by interconnection (tie-line) metering and telemetry. The Control Area controls generation directly to maintain its interchange schedule with other Control Areas and contributes to frequency regulation of the Interconnection.

Interconnection may refer to any one of the bulk electric system networks in North America: Eastern, Western and ERCOT, and may also refer to Quebec electric system network. When not capitalized, it may also refer to facilities that connect two systems or Control Areas.

FIG. **5** is a block diagram that illustrates the integration into power generation, transmission and distribution of the power grid monitoring and management system in an exemplary embodiment according to the present invention. The top part of FIG. **5** illustrates that the current business model is segmented into generation, transmission, distribution, markets and security. It can be seen here that the vertically integrated business model historically used by utilities has evolved to a segmented market dispersed among separate entities.

The power grid monitoring and management system has been developed to serve as the base for the development of reliability applications for real-time monitoring, tracking and prediction for the reliability performance of Control Areas, generation, grid, markets, and security. Control Area's ACE, interconnection's frequency and interchange data on top of the power grid monitoring and management system provide a common tool to be utilized by NERC Reliability Coordinators, Control Area Dispatchers, and Transmission Dispatchers. The bottom of FIG. **2** also shows that reliability applications developed using the power grid monitoring and management system may serve as complement for traditional SCADA/EMS systems and for the periodic reporting requested by NERC for post performance.

As can be seen in FIG. **5**, various different data are provided by generation **10**, utilities **20** (transmission **12** and substations **14**), market **16** and security **18**. These data, such as generation data, grid data, market data and performance data are provided to one or more various different organizations **22** such as, for example, ISOs, RTOs, transmission companies, Control Areas and the like.

One or more of these organizations perform real-time operations **24** such as scheduling, dispatching, system security, ancillary services and the like. Also, one or more of these organizations perform assessment and reporting **26** such as reports to reliability authorities such as ISOs, RTOs, FERC/PUCs and NERC.

As illustrated in FIG. **5**, the power grid monitoring and management system in the described exemplary embodiment provides an infrastructure for integrating the monitoring and control of real-time operations, assessment and reporting provided by various different entities using data provided by still other various different organizations.

FIG. **6**, for example, shows an expansion of the power grid monitoring and management system **28** from FIG. **2** and includes the major reliability applications for real-time reliability monitoring for NERC Reliability Coordinators and Control Area Dispatchers. The top part FIG. **3** shows the applications target for Reliability Coordinators, ACE-frequency, AIE and control performance standards (CPS). The bottom part of FIG. **6** shows the applications target to Control Area Dispatchers, performance compliance of Control Areas, suppliers to AGC, FRR and ancillary services markets.

As can be seen in box **30**, NERC Reliability Coordinators monitor several requirements, including ACE-Frequency, to maintain and enhance the reliability of their jurisdictions. The ACE-Frequency Monitoring System, shown in the upper applications box (Reliability Region Performance Monitoring Platform) **34**, provides applications for each Coordinator within each of their Reliability Regions. Reliability Coordinators utilize those applications to monitor performance and compliance within their Regions and notify the appropriate Control Area Dispatchers as abnormalities occur. Control Area Dispatchers pinpoint problem sources by monitoring the response performance of their Control Area and suppliers to AGC monitoring system, frequency response resources and ancillary services.

For example, in one exemplary embodiment, the power grid monitoring and management system may be described in reference to performance monitoring, tracking and short term prediction of California Independent System Operator (CAISO) Control Area and suppliers response to AGC, frequency response reserves (FRR) and ancillary services application as shown in box **36** (Control Area Performance Monitoring Platform) to support Control Area Dispatchers Monitoring Requirements (**32**). This application represents further progress towards grid reliability technologies and management tools that present real-time performance, tracking and predictive information across several spheres of grid operating and reliability concerns.

FIG. **7** illustrates an application of the power grid monitoring and management system **40** in an exemplary embodiment according to the present invention. The power grid monitoring and management system includes a platform to support RTO functions (**42**) such as markets, operations, security and reliability monitoring.

FIG. **8** illustrates functions of the power grid monitoring and management system **50** in an exemplary embodiment according to the present invention. The power grid monitoring and management system **50** includes a platform for performing one or more of real-time performance monitoring **52**, historical performance tracking **54**, sensitivities and short term prediction **56**, and action & simulations for reliability and markets **58**.

As part of the real-time performance monitoring **52**, the power grid monitoring and management system may monitor one or more of voltageNAR, ACE-Frequency, transmission congestion, generator performance for AGC and frequency response and market prices/spikes.

For historical performance tracking **54**, the power grid monitoring and management system may track one or more of Interconnection, Generator, Region/Zone/Substation as well as market.

As part of sensitivities and short term prediction **56**, the power grid monitoring and management system may predict/handle one or more of system demand, generator response, voltage sensitivities, distance from collapse and short term predictions.

The actions and simulations **58** performed by the power grid monitoring and management system may include one or more of notifications, reserves & ancillary services, capacitor dispatch, generation re-dispatch, VAR management and automatic mitigation.

FIG. **9** is a local area network (LAN) **100** based hardware and software architecture for the power grid monitoring and management system in an exemplary embodiment according to the present invention. The architecture includes a number of clients **114**, **124** that interface with a server **110** over the LAN **100**. The server and clients, for example, may be COM+ server and clients, and the communications may take place using XML language.

Each client **114**, **124** interfaces with the power grid monitoring and management system client **116** and **126**, respectively. The display of the power grid monitoring and management system **118** and **128** are used to provide visual indication of monitoring and tracking to the user.

The server **110** is coupled to a power grid monitoring and management system database **104**, for example, over an OLEDB connection. The server **110** is also connected to a power grid monitoring and management system application

server **102** and a client **108**. The communication between the server **110** and the client **108**, for example, is performed using XML language. Further, the client **108** communicates with one or more monitoring applications **106** using the XML language. The one or more monitoring applications **106** also interface with the power grid monitoring and management system application server **102**. The monitoring applications are connected over OLEDB connection and/or other data base connections to customer proprietary databases or data platforms **112**. The customer proprietary database or data platform **112** may include one or more of SCADA (Supervisory Content and Data Acquisition) database, market database, PI database and Phasor Data database. The LAN-based architecture may have different configurations in other embodiments.

FIG. **10** is a web-based hardware and software architecture for the power grid monitoring and management system in another exemplary embodiment according to the present invention. On the power grid monitoring and management system application server side, the configuration is identical to that of the LAN-based hardware and software architecture. The server **110**, however, communicates with another client (which may be a COM+ client) **142** using the XML language. The client **142** is coupled with an Internet Information Server (IIS) **140**. A power grid monitoring and management system web server **144** also communicates with the client **142** and the IIS **140**. The IIS **140** communicates over the Internet **150** using XML language and Simple Object Application Protocol (SOAP) protocol with the visualization programs **152** and **156**, respectively, for visual communication with users on web clients **154** and **158**, respectively. The web-based architecture may also have different configurations in other embodiments.

For example, in both the architectures of FIGS. **9** and **10**, only two clients are shown on the client side. In practice, however, there may be more than two clients. Further, the power grid monitoring and management system application server **102** may be coupled to both the LAN-based clients and web-based clients over the LAN and the Internet, respectively. Further, the Internet may be replaced or complemented by an Intranet or any other similar proprietary or non-proprietary networks.

FIG. **11** illustrates the architecture of an ACE-Frequency real-time monitoring application **160** using the power grid monitoring and management system in an exemplary embodiment according to the present invention. The ACE-Frequency monitoring system receives ACE and frequency data from the nation's Control Areas (Data Collection **162**), calculates performance parameters (e.g., reliability compliance parameters **170**) for each reliability jurisdiction and compares those performance parameters to NERC reliability compliance guides (Standards & Algorithms **166**). The results of these comparisons are then displayed graphically and (Visualization **164**) on a geographical map (Geography **168**) for use by each of the Reliability Organization from each of the layers, depicted in the lower, right pyramid **172**. The tiers of the pyramid comprise the control areas, reliability coordinators, reliability transmission organizations, reliability regions, and Interconnections.

FIG. **12** illustrates five major functional components of the NERC ACE-Frequency real-time monitoring system **180** in an exemplary embodiment according to the present invention: Local Monitoring **182**, Global Monitoring **184**, Abnormal Frequency Notification (AFN) **186**, Interactive Data Collection (IDC) **188** and Unavailable Data Reporting (UDR) **190**. Following are description of each one of the major functional components.

The first is the Local Monitoring Geographic-Graphic Visualization **182**. In the described exemplary embodiment, most of the ACE-Frequency visualization is geographic-graphic oriented and covers different time windows from current time to 30-days. The local-visualization option covers from current time to 1-hour, and it offers to end users three different views of Control Area ACE and Interconnection frequency data displayable in the three-panel window visualization.

The second is the Global Monitoring Geographic-Graphic Visualization **184**. In the described exemplary embodiment, this option uses the Epsilon performance parameter as an indicator of the frequency performance for each of the interconnections. For example, it shows the performance parameter for two time windows, 6-hours and 30-days. It also uses a power grid monitoring and management system three-panel window visualization as will be described below.

The third is the AFN **186**. The real-time AFN is a real-time monitoring component of the ACE-Frequency Monitoring System. The AFN is designed for real-time monitoring of abnormal interconnection frequencies, and to automatically issue e-mails to specific NERC Resources Subcommittee members and NERC staff when predefined abnormal frequency performance criteria are met. E-mail recipients may, for example, use the ACE-Frequency monitoring system capabilities to assess root causes of the abnormal frequencies when notified. The input data to the AFN may be provided by Control Areas to NERC over a secure connection using NERCnet, XML, and/or SOAP technologies.

The fourth is the IDC function **188**. Via the IDC functionality, NERC subcommittees, NERC staff, and operating engineers can interactively define the historical window of time and the specific control-performance parameter they need to analyze and assess frequent disturbances. Once data is collected from the NERC data server, the users can use equivalent reliability coordinator visualization and/or save the data in comma-delimited files.

The fifth is the DRG function. The DRG offers the capability to interactively identify and report Control Area data transfer performance. Users can select hourly, daily, weekly, and/or monthly reports and select the specific data they want to assess for availability.

It has been demonstrated by Control Area Dispatchers that the more effective operational displays are those that follow a hierarchical approach to present operational data for current time and other key windows of time. The power grid monitoring and management system visualization model in an exemplary embodiment of the present invention encompasses displays at high and low levels to meet the varying needs of different reliability application users. Thus, in the described exemplary embodiment, monitoring applications are developed for wide-area and local area users using the power grid monitoring and management system.

FIG. **13** illustrates reliability functional levels and visualization hierarchy in an exemplary embodiment according to the present invention, and FIG. **14** illustrates an integrated visualization model in an exemplary embodiment according to the present invention.

The hierarchal structure in FIG. **13** shows that it is desirable for the Reliability Coordinators to have a wide-area view of their jurisdictions for reliability compliance monitoring **192**. Also, it is desirable for the ISOs and RTOs to have the ability to assess performance and trends (**194**) of their Control Areas. In turn, it is desirable for Control Areas to have local area information **196** to pinpoint specific suppliers reliability performance issues. The ACE-Frequency tool allows Reliability Coordinators to monitor ACE-Frequency performance and

compliance for each of their jurisdictions using wide-control-area graphic-geographic visualization.

For the definition and design of the ACE-Frequency graphic-geographic visuals for each of the visualization layers shown in FIG. **13**, the data collection **200**, computational and display (or visualization) models **202**, **204** from the power grid monitoring and management system shown in the first three vertical segments on FIG. **14** may be used. For the NERC ACE-Frequency real-time monitoring system, about 123 Control Areas transmit ACE and frequency data to a data server located at NERC (data collection).

The data is processed and performance parameters are calculated in the computational engines (computational model) of the power grid monitoring and management system. The design and deployment of each of the displays follows the three steps (i.e., human factors, user interaction and composition) illustrated in the display model section **204** on FIG. **14**.

FIG. **15** illustrates an ACE-frequency real-time monitoring architecture of the power grid monitoring and management system in an exemplary embodiment according to the present invention. For example, input data is provided by Control Areas to NERC over a secure connection using NERCnet **211** during data acquisition and validation **210**. The data may have been sent, for example, by one or more (up to all) of 123 Control Areas. The received data is archived (i.e., collected and concentrated) in one or more NERC database servers **216**. The data may also be processed using ACE and/or AIE applications. Output results go, for example, via XML, and SOAP technologies to a browser base clients.

The archived data may also be provided to NERC applications and web server **218**. The NERC applications and web server communicate with an early notification e-mail server **222** and/or Reliability Authorities web browser **220** over the Internet. For example, The NERC applications and web server may broadcast ACE-AIE key data to the Reliability Authorities every 60 seconds. The early notification e-mail server **222** may be used to notify abnormal events via e-mail **212**. The monitoring and tracking by 22 Reliability Authorities may include graphic and geographic displays using the performance monitoring technology platform of the power grid monitoring and management system of the present invention.

FIG. **16** is a screen shot **220** that illustrates a multiple view architecture of a display of the power grid monitoring and management system in an exemplary embodiment according to the present invention. The screen shot includes a real-time monitoring panel **222** used for graphical monitoring, a tracking panel **224** used for displaying tracking information, and a forecast panel **226** used for displaying prediction. The screen shot **220** also includes a text data/horizontal scroll panel **228** for viewing/scrolling text data.

In an exemplary embodiment according to the present invention, the CMS of the power grid monitoring and management system provides to Security Coordinators the tools to monitor each Control Area (CA) within their area of responsibility. Using the CMS, each Control Area will be reporting their ACE and AIE. For example, each of the Control Areas may report in one-minute intervals its ACE, frequency and AIE data through the NERCnet to the NERC Web Server. This data may be matched to the ACE/Frequency validation Matrix, the ACE-CMS database and presented back to each Security Coordinator utilizing the CMS. The compliance monitoring (reliability compliance) may also include CPS monitoring and inadvertent monitoring.

Therefore, the Security Coordinator will have the ability to view the CA performance using the graphic geographic visualization for Interconnections, Reliability Regions, Reliability Authority, Control Area and RTOs. Within these graphic displays the local hourly ACE may be presented in 2D and/or 3D. The power grid monitoring and management system also allows the user to display the ACE over different periods of time. These periods of time may range from the last scan to a thirty day history. The selection of all the Control Areas to an individual Control Area may be available to the user. In the described exemplary embodiment, there are three basic views for use in viewing these areas. An interactive replay of historical data may also be available. The replay element may, for example, allow for 24 hour, 48 hour, 7 day and 30-day replays.

The exemplary CMS presents the user with several different graphics. The Cave diagram is one of those graphic that is used as a tool to represent frequency/ACE, frequency/CPS**1** and Epsilon**1**/calendar. The CPS**1** pertains to a limit, which is a constant derived from a targeted frequency bound reviewed and set as necessary by the NERC Performance Subcommittee. Over a year, the average of the clock-minute averages of a Control Area's ACE divided by −10□(□ is control area frequency bias) times the corresponding clock-minute averages of interconnection's frequency error must be less than this limit to comply with CPS**1**. To comply with CPS**2**, the average ACE for each of the six tem-minute periods during the hour (i.e., for the ten-minute periods ending at 10, 20, 30, 40, 50 and 60 minutes past the hour) must be within specific limits, referred to as L**10**. An Epsilon (□) is a constant derived from the targeted frequency found. It is the targeted root mean square (RMS) of one-minute average frequency error from a schedule based on frequency performance over a given year.

The Cave diagram **230** in FIG. **17** represents a Frequency/ACE diagram. Time is displayed on the horizontal axis. The upper graph vertical axis **232** displays the ACE. The lower graph vertical axis **234** displays the frequency. These two elements are used to develop the Cave graph. This type of graph is used as a tool for the review of current data as well as historical data in an exemplary embodiment according to the present invention.

The ACE function allows the user to view data for Epsilon**1**, ACE, and CPS**1**. Hence, the user is allowed to view the global, local or tracking data depending on what the user requires can disseminated the data further. The global function may be used to look at one or more of the Epsilon, the local ACE and tracking CPS**1**.

Referring back to FIG. **11**, the CMS receives data from the Control Areas (Data Collection **162**) and compares this received data to the submitted compliance data from each Control Area (Standards & Algorithms **166**). The results of these comparisons are then displayed graphically (Visualization **164**) on a geographical map (Geography **168**). The five tiers of display start with the ISO RTO, Control Areas Reliability Authority, Reliability Regions and Interconnections.

FIG. **18** is a screen shot **240** of a default display for a Reliability Authority in an exemplary embodiment according to the present invention. The boundary tabs that appear at the top left side of screen represent the reliability organizations entry points. The five boundary tabs that are used for the CMS in the described exemplary embodiment are as follows: 1) Interconnections; 2) Reliability/Regions; 3) Reliability Authority (default); 4) Control Area; and 5) ISO RTO.

The Interconnection Map is divided into the four (4) NERC Interconnections, West, East, Quebec and Texas. The Reliability Region tab allows the user to view the map in a Region format. The Reliability Authority tab allows the user to view the 20 Reliability Authority areas of responsibility. Further, the Control Areas tab will give the user a map of all the NERC

Control Areas. In addition, the ISO RTO map displays the thirteen (13) RTOs. In each of these maps, the Interconnections and/or other areas that do not submit data to the CMS are shown in black. In FIG. **18**, for example, Texas is shown in black as it is not currently submitting data to the CMS.

In each of the five boundaries, the current ACE and ACE/L**10** data is displayed. The corresponding data is presented in a dynamic window **244** that appears at the bottom center of each map. As shown in FIG. **18**, the dynamic window has four tabs: 1) Overview; 2) Worst/Best CA's; 3) Reliability Authority Data, which changes to the boundary selected); and 4) Control Area (inner circle).

In the power grid monitoring and management system of the described exemplary embodiment, a 3D map may also be displayed. In addition, the network lines may be generated on the map. Further, the user may also be able to view global Epsilon for the Interconnections. Epsilon is a function of frequency. It is a constant derived yearly from the targeted Interconnection frequency deviations found from the prior year. This constant is used to compare the last hour frequency performance against this constant, and used to assist the Regional Authority on knowing how the Interconnection control has performed. For example, when the constant and measured value equal a number between 0-8 the map may be colored in blue ("good") for that Interconnection. Should the comparison of the Epsilon be greater than 8, but less than 10 then that Interconnection may appear as green ("satisfactory") on the Interconnection map. Similarly, the Interconnection may appear yellow ("warning") between Epsilon of 10-11 and red ("violation") for Epsilon greater than 11.

The Epsilon for the selected one or more Interconnections for the past 24 hours may be viewed, for example. FIG. **19** is a screen shot **250** of an Interconnect-Epsilon map in a three-panel display in an exemplary embodiment according to the present invention. It can be seen in a first panel **251** that the United States is divided into four Interconnections: 1) Western (W) **252**; 2) Eastern (E) **253**; 3) ERCOT (T or Texas) **254**; and 4) Quebec (Q) **255**.

The user may select one or more Interconnections for view. In the screen shot **250**, the "Daily Interconnection Map—Last 24 Hours Epsilon" **251** occupies the first panel. The "Daily Image Panel" **256** is in the upper right hand corner, and the "Daily Plot Panel" **258** is located in the lower right hand corner of the display. To have any one of the panels viewed as a full screen for better viewing, the desired panel may be right clicked to bring up a pop-up menu. By selecting "Maximize", the Panel may be shown as a full screen. The power grid monitoring and management system also allows for replaying using a replay function, for example. The replay may be up to 24 hours or more, for example. The replay speed may also be controlled to be slower and/or faster.

FIG. **20** is a screen shot **260** of a local view for a Control Area map in an exemplary embodiment according to the present invention. The graphic in the view of FIG. **20** shows the ACE and ACE/L**10**. The Control Areas' ACE and/or ACE/L**10** may be color coded so that as the Control Area's "ACE" changes the colors may be represented for the Control Area. For example, the ACE of −200 to −100 may be represented by red, −100 to 0 by yellow, 0 to 100 by green and 100 to 2000 by blue.

Also for the local view, a three-panel display may be displayed for a specific Control Area. The adjacent Control Areas may be defined as two Control Areas that are interconnected: 1) directly to each other; or 2) via a multi-party agreement (e.g., ISO and Power Pool agreements) or transmission tariff. Selecting Adjacent **0** may show only the Control Area, Adjacent **1** may show adjacent Control Areas, and Adjacent **2** may go out to the second level out away from the selected Control Areas. Selecting All may select all Control Areas. An actual interchange is a metered interchange over a specific interconnection between two physically adjacent Control Areas. An inadvertent interchange is a difference between the Control Area's net actual interchange and a net scheduled interchange.

For example, FIG. **21** is a screen shot **270** of a current Control Area map for a selected Control Area **272** in an exemplary embodiment according to the present invention. The selected Control Area **272** is shown in yellow on the ACE map. The upper right hand corner shows a last hour ACE **274**. This display is broken into 10-minute increments. A Cave graph **276** displays frequency and ACE for the last hour. The last hour ACE and the hourly Cave may also be displayed separately in the full screen. Similar to the global view, the local view ACE may be replayed for last 24 hours or more, during which the replay speed may be adjusted to become faster and/or slower.

FIG. **22** is screen shot **280** of a CPS map in an exemplary embodiment according to the present invention. The CPS map in the described exemplary embodiment is the same for each of the five boundary tabs. The CPS map may be color coded to visually give the user, for example, a view of the number of items in the ten (10) minute window of CPS**1** that the ACE did not cross zero for the last hour when compared to the Control Area's stated CPS**1**. For example, blue may represent 0 to −100%, green may represent 0 to 100%, yellow may represent 100% to 200%, and red may represent 200% to 1,000%.

By selecting the Control Area, and selecting a daily or monthly view, a three-panel view may be obtained for the Control Area and/or adjacent areas. For example, FIG. **23** is a screen shot **290** of a three-panel view in an exemplary embodiment according to the present invention. This particular map, for example, was generated using Adjacent **1** feature. From this screen, a replay of last 24 hours or more may be obtained. Further, the replay speed may also be controlled to be faster and/or slower.

FIG. **24** is a screen shot **300** of a data collection tool in an exemplary embodiment according to the present invention. The data collection tool may allow the user to view/extract raw data from the NERC database. This tool may be used to view the data that has been collected for the user to analyze. Using the collected data, one or more charts may be generated as shown on a screen shot **310** of FIG. **25**, for example.

FIG. **26** illustrates utilization of NERC ACE-frequency monitoring **315** in an exemplary embodiment according to the present invention. The power grid monitoring and management system receives an early abnormal notification **320**. Then a root cause assessment **322** is performed for Regions and Control Areas with ten (10) worst ACEs, for example. Of these Regions and Control Areas, the root cause is pinpointed (**324**). Further, the Interconnection Control Areas Frequency-ACE and Root Cause Control Area ACE-Frequency are analyzed (**326**, **328**).

FIG. **27** illustrates a screen shot **330** of a supplier-Control Area performance for AGC and frequency response application in an exemplary embodiment according to the present invention. For example, as can be seen in a first panel **332**, real-time monitoring can be performed by zones, resource types and/or by owner. Actions/results may be viewed through horizontal scrolling and/or tabular display **338**. Further, a simulation or replay may also be performed/displayed. In the other panels **334** and **336** of the three-panel display, a historical performance tracking and delta forecast for the next six (6) ten minute periods, respectively, are also displayed.

FIG. **28** illustrates a market monitoring system **340** in the power grid monitoring and management system in an exemplary embodiment according to the present invention. In the market monitoring system **340**, a market monitoring center **342** (in the power grid monitoring and management system) receives systems conditions **344** such as market power, price spikes, demand forecast error, safe regulation bands and/or new control metrics. Also, the market monitoring center **342** receives market metrics such as blue alert, green alert, yellow alert and/or red alert. Then the market monitoring center performs actions **347** such as market performance metrics notification, remedial actions (e.g., re-dispatch), emergency actions and/or suspend rules. Further, the power grid management system monitors system conditions, track market metrics, assess predictive risk management, and the like (**348**).

FIG. **29** illustrates a screen shot **350** of a market monitoring application (of the power grid monitoring and management system) in an exemplary embodiment according to the present invention. For example, the system monitors (**352**) prices/spikes, imbalance energy, market power indices, and/or demand forecast error. Further, the system is used to take corrective actions (**354**) such as re-dispatch, price caps, suspend market rules and/or automatic mitigation. In two other panels of the three panel view of FIG. **29**, the system also tracks (**356**) historical performance by generator, control area, market and/or supplier, and/or the like, and bid sensitivities (**358**) for generator, portfolio and/or Control Area.

The power grid monitoring and management system in an exemplary embodiment according to the present invention performs Security Center monitoring. The Security Center operational hierarchy may include one or more of: 1) Security Monitoring Center using current and future synchronized data; 2) NERC **22** Reliability Coordinators; 3) RTOs/ISOs, Control Areas; 4) transmission only providers; 5) generation suppliers; and 6) load serving entry.

FIG. **30** illustrates a Security Center monitoring system (of the power monitoring and management system) in an exemplary embodiment according to the present invention. A Security Center **362** receives composite security indices **364**, which include synchronized data network, supply adequacy metric, voltage/VAR adequacy, congestion management and/or market dysfunction. The Security Center also receives security alerts **366**, which include red, orange, yellow, green and/or blue alerts. The Security Center **362** in coordination with a Security Coordinator **367** tracks composite security indices **368**, monitors composite security metrics **372**, assesses predictive risk management **374**, and coordinates with Reliability Coordinators level **370**. FIG. **31** illustrates a screen shot **380** of a real-time security monitoring application (of the power grid monitoring and management system) in an exemplary embodiment according to the present invention. The system performs a real-time monitoring of composite security indices (**382**), and also tracks the composite security indices (**388**). In addition, the system coordinates with NERC Reliability Coordinators. Further, the system also provides actions, phone numbers and e-mails to facilitate the coordination (**386**).

FIG. **32** is a block diagram of a NERC reliability functional model **390** in an exemplary embodiment according to the present invention. The power grid monitoring and management system in exemplary embodiments according to the present invention facilitates the integration process, focusing first on the applications required by the stakeholders within a dotted line **392**. Functions within the dotted line include reliability coordination **393** and compliance enforcement **394**, balance authority service acquisition **395**, load servicing entities procurement **396** and the actual usage of the services by the transmission operators **397**.

In an exemplary embodiment according to the present invention, the power grid monitoring and management system is adapted for the monitoring, tracking and short term prediction of CAISO CA and suppliers response to AGC, FRR, and ancillary services (A.S.) regulation performance/requirements. In the described exemplary embodiment, the power grid monitoring and management system will track and predict both the Control Area's and the supplier's performance for the above three services (AGC, FRR and A.S.). The power grid monitoring and management system, for example, may be used by the real-time operators, the operating engineering staff and/or management.

The real-time operators may obtain one or more of the following benefits through the present invention: 1) enhanced ability to monitor and track the CAISO Control Area and Suppliers response to AGC, including the ability to segregate into areas, (e.g., Northern and Southern California) and suppliers; 2) identify Control Area and supplier's actions, their performance and near real time predictions to frequency response; 3) identify and provide information for possible required changes in next hour's scheduled A.S. for Regulation; 4) identify and provide information for possible required changes in next day's scheduled A.S. for Regulation; and 5) one general overview display that show all three functions. More detailed displays may be available for each area.

The operating engineers may reap one or more of the following benefits from the power grid monitoring and management system of the present invention: 1) provides them with unit specific performance information; and 2) provides them with information that allows them to work with plant owners to improve their response to AGC, FRR and A.S. Regulation. Further, the power grid monitoring and management system of the present invention may provide to the management near real-time operational information that allows them to evaluate the effectiveness of market rules and tariffs.

The power grid monitoring and management system may also provide reliability services to the relationships between operational reliability objectives, services required for reliable operations and the roles and responsibilities for the control and operation authorities. For example, the reliability services may be provided to transmission reliability, supply resources and demand balance, and A.S. markets.

Returning now to FIG. **6**, the top half of FIG. **6** shows the architectural overview of the application of the power grid monitoring and management system for monitoring real-time control performance at the reliability coordinator level. The applications have been designed, deployed and tested for the NERC Reliability Coordinators. The bottom half of FIG. **6** shows the overview for the Control Area level. The power grid monitoring and management system integrates response to AGC, FRR and A.S. to effectively visualize how the CAISO Control Area and Suppliers are performing for each of the three areas.

A System operator normally has an available range of AGC control, both up and down, displayed on some type of general overview. These values, in today's systems, are normally mapped into these overviews as provided by successful bidders of Regulation A.S. This AGC range & ability governs many decisions made on real time (i.e., magnitude of Control Area Interchange ability, coverage of manually directing online generators for various reasons, etc.). In one exemplary embodiment, the AGC module of the power grid monitoring and management system qualifies the accuracy and performance of that AGC range as it happens and records it. For

example, the AGC module may display and track how much a generator on AGC control is signaled to move in MW and presents various displays/documentation on how well (or not) that requirement is/was being met.

The user may have the ability to see generator response to AGC in real-time. Aside from over-all aggregate views, the user can display (select or "turn on") a segregation of generators into zones (e.g., Northern California and Southern California) and suppliers, which could aid real-time decisions. As an example, monitoring could show all generators in the north meeting 100% response requirements and only 70% in the south, dictating possible manual intervention for an upcoming large ramp that might leave undesired loadings on constrained paths (e.g., Path **15**). Aside from regional segregation ability, the power grid monitoring and management system can also separate displays into types of generators (i.e., 150 Mw, 750 MW, Hydro, etc.).

The displays for tracking may show the response performance of suppliers to AGC for the previous hour, day and week. By utilizing historical response data, the application may predict the response performance of each supplier to AGC for the next 10, 20, 40 and 60 minutes.

In Summary, the AGC module may achieve/produce one or more of the following: 1) a visual representation of the real-time performance of each generator on AGC; 2) various options of displaying aggregate and detailed information on AGC units; 3) provisions for alarm points when established parameters are met; 4) selectable Time Period Displays and Printouts, (Previous Hour, Day, Week) of a generator's performance. They can be used for monetary penalties in billing and for various analysis efforts; and 5) can be used for near real time prediction. (10, 20, 40 and 60 minutes). The system overview visualizations to show the above functionalities will be discussed later.

In an exemplary embodiment according to the present invention, the power grid monitoring and management system provides control area and suppliers response performance monitoring, tracking and prediction to FRR. Historically, having NERC Standards in place has provided adequate assurance that the Control Areas and interconnected generators within each Interconnection, as well as load shedding, were able to effectively respond to contingencies and adequately arrest frequency excursions, thereby meeting design expectations. Within the WECC (i.e., Western Interconnection), the normal and expected change in system frequency for the loss of 1,000 MW of generation has been a 0.1 Hz decay. In recent years, however, it is not unusual to experience a 0.1 Hz decay in system frequency with only a 300 or 400 MW loss of generation. So FRR Monitoring, Performance Tracking and Prediction implementation at CAISO is desirable.

The following example illustrates a frequency decay by 0.2 Hz for a loss of about MW. It appears, for whatever reasons, that the overall frequency response of the interconnected system has changed significantly, in a negative way. The exemplary embodiment implements new standards, specifically addressing the issue of frequency response, and establishing the necessary monitoring and tracking system(s) to evaluate the performance of the frequency responsive resources and the Control Area.

A Control Area's frequency response performance is the result of how good or bad all the Frequency Response resources connected to the transmission system respond and perform. This application will monitor, track, and project Frequency Response Reserves performance in the CAISO Control Area.

Major functions of the FRR module may include one or more of:

1) Performance—monitor the performance of the CAISO's Control Area response to frequency excursions, calculate the MW/0.175 Hz deviation and determine if the Control Area is in compliance with the proposed NERC/WECC FRR standards. In addition, the application may monitor the actual performance of each of the frequency responsive resources that are expected to support the Control Area response to frequency excursions and calculate their contribution per MW/0.175 Hz deviation. This module will provide the answer to the question, "Which resources are contributing to the Control Area's overall compliance with the Frequency Response Reserves (FRR) standards?";

2) Tracking—time tagging and archiving of actual data associated with monitoring performance and MW/0.175 HZ deviation performance of the Control Area to frequency excursions, as well as the performance of the individual frequency responsive resources. Data may be stored in a time series database and used to present the pattern and behavior of specific resources. Historical data may also be used to feed the prediction module. It can also be an ingredient of any required disturbance control standard (DCS refers to the standard which requires the ACE to return either to zero or to its pre-disturbance level within 15 minutes following the start of the disturbance, which is a) any perturbation to the electric system, or b) an unexpected change in ACE that is caused by the sudden loss of generation or interruption of load);

3) Probabilistic prediction—provide the CAISO staff with a prediction of the expected performance of the frequency response resources to the next frequency excursion. A more accurate forecast of the upcoming performance in meeting the FRR standards may allow the CAISO to maintain and improve system reliability and market efficiencies. If the prediction module of the application determines that the anticipated resource configuration is inadequate in meeting the FRR requirement, it can produce a suggested alternative or additional resource requirements; and

4) Visual Analysis—the power grid monitoring and management system visual analysis layer may facilitate the interpretation of the results from each of the major functions. Taking advantage of the visualization technology available in the power grid management system, it may present past, current and near term future information to the CAISO staff on tabular, graphical and/or geographical displays. The application may provide the ability to segregate suppliers into zones, such as Northern & Southern California, and also of the various "types" of generators.

Load shedding on non-critical loads is another FRR resource that the system operator may have to adjust frequency. For this reason, the performance of load shedding (measured as MW/0.175 Hz) as a frequency control resource may also be determined, tracked and predicted.

The suppliers response performance to AGC previously explained, displayed and recorded what each and all Control Area regulating generators were signaled to move and how they performed, relative to that signal. This application may track and record the delta or difference between what the supplier bid in regulation service for the Hour Ahead Market and its actual response.

Ancillary Service of regulation is normally prescheduled for the hour ahead (and day ahead) via the marketplace. A successful supplier of regulation will normally have an up and down magnitude, although one direction only can occur. In conjunction with that MW range, a ramping (rate of change) magnitude is also provided by the supplier, normally in percentage or MW/minute.

The displays for monitoring of this application will show and record how well a generator is providing regulation, follows control signals sent by CAISO's Energy Management System Computer and will compare it to the parameters (ramp rate) provided by the supplier (Bid, Contract or Plant Information) in the Hour Ahead or Day Ahead Market.

The displays for tracking will show the supplier's historical response performance to the hourly ancillary services market for the last day and week. This information could be shared with the suppliers that provide this service, to improve quality, or even be made inclusive of the payment structure when stipulated non-performance occurs.

The displays for prediction will show the suppliers predictive response performance to hourly ancillary services one, two, three and/or four hours ahead. For example, suppose next hour's Regulation range is displaying a 500 MW upward quantity, with a 25 MW/Min aggregate ramp rate, provided by the marketplace. Utilizing historical performance data, this application will note what sources are providing this regulation range and "quantify" it for the System operator. It could, for example, note that only x-amount is available over a designated time period or that only 15 MW/Min rate of change is achievable. If that reality is unacceptable, the system operator may have the option of utilizing other hourly or 10 minute sources to mitigate adverse balancing and reliability effects. This will apply to either increasing or decreasing load requirements.

A System operator will often have a need to appraise what resources have been planned for some near short term future hours. This can be the result of unplanned outages of generators, internal transmission lines, interconnection transmission lines and other events. This application gives a little longer look than the Hour Ahead program in respect to Ancillary Services Regulation.

Similar to the Hour Ahead function, the monitoring associated with this module is focused on those regulation ancillary services that were attained from the Day Ahead Market only and will display relative comparisons of actual performance vs. market bids in these regulation services.

Historical performance data for the past day and week will be available in the displays of this module. This data could be used in conjunction with the Hour Ahead Performance by comparing records for various validations or determinations between the two markets. They can also be shared with the suppliers for improved quality of service or included in the payment structure for performance penalties. The power grid management system may also allow the user, using historical performance data, to predict the performance of the day ahead committed resources of ancillary services for regulation by choosing the display option of Day Ahead Market.

Based on NERC current reliability guides, drafts standards for NERC and WECC Frequency Response Reserves (FRR) and input from the CAISO's system operators and management, the key functional capabilities for the power grid monitoring and management system for CAISO may include one or more of: 1) performance monitoring of CAISO's CA and suppliers to AGC; 2) performance monitoring of CAISO's CA and suppliers to FRR; and 3) performance monitoring for CAISO's CA and suppliers to Hourly and Day-Ahead Ancillary Service Regulation.

The Control Area's frequency response performance is the result of how good or bad all the frequency responsive resources connected to its transmission system perform. The challenge for the Control Area is how to determine the actual performance of each resource vs. expectations.

Although this application has the ability and will evaluate the Control Area performance to determine compliance with

the FRR Standards, the primary focus of the application is to monitor and track the actual performance of the individual frequency responsive resources connected to the grid. As stated above, it is the performance of each and every resource connected to the CAISO's grid that will determine the Control Area's overall frequency regulation performance.

The purpose of the proposed application is to provide sufficient and meaningful information for the CAISO management and staff to: 1) maintain system reliability and ensure compliance with NERC and WECC reliability standards, by monitoring in real time the response performance of CAISO's CA and suppliers to the AGC, FRR and A.S.; and 2) improve the efficiency of the A.S. market. The Table 1 below, for example, shows functionalities in an exemplary embodiment according to the present application.

TABLE 1

Overview of Functionalities

Function	Service: CA&Suppliers Response to AGC	Service: CA&Suppliers Response to FRR	Service: CA&Suppliers Response to A.S.
Monitoring	Scheduled vs actual response in last one-minute interval Performance Indices	Expected vs actual response in last frequency excursion Performance Index	Last Bid vs actual response Performance Index
Tracking	Previous hour, day and week scheduled vs actual response Historical Performance Index	History of Deviations (MW/0.175 Hz) performance to frequency excursions of CA and suppliers Historical Performance Index	Last day supplier response to A.S. markets Last week supplier response to A.S. markets Historical Performance Index
Predictions and Probability bands	10 Minutes Ahead 20 Minutes Ahead 40 Minutes Ahead 1 hour ahead Probability bands Bad data identification and replacement	Next frequency excursion, twenty and sixty seconds response Probability bands Bad data identification and replacement	1, 2, 3 and 4 hours ahead for hour market Day ahead market Probability bands Bad data identification and replacement

It should be noted that the tracking function may serve as a simulation tool.

In monitoring the response performance to AGC of CAISO CA and suppliers, the system operator may first look at the display of the one-minute supplier control error for each resource. A pie graph may be presented for each resource that is being monitored. Part of the pie indicates the expected response, other part the actual response and the last part the difference between the actual and the expected response. The pie will be color coded to indicate the performance of the generator response for the last one-minute period. The cylinder height, also color-coded, represents the performance index. The performance indices are defined herein later on.

For the tracking of the response performance to AGC of CAISO CA and suppliers, the system operator has a chart available with the historical values for the period that he/she specifies. The response prediction may also be offered to the System operator, for the next 10, 20, 40 and/or 60 minutes.

The system operator may then use these three pieces of information to decide how much to rely on each resource for

AGC. For example, suppose actual part of the pie is red and the cylinder height is red. This means that the supplier is performing poorly recently. Analysis of the historical performance (tracking function) provides additional information to decide how reliable the supplier is. If the historical performance is poor, the forecast will also be poor. The System operator will integrate all this information to decide on a course of action for the resource under consideration.

Similar functionality will be offered for monitoring, tracking and predicting the response performance of CAISO CA and suppliers to FRR. Instead of one-minute values as in the resource response to AGC, however, the resource response to the historical average to frequency excursions may be displayed. Each supplier may be represented by two color-coded pies and a cylinder. The pie indicates the generator FRR actual response to the last frequency excursion and its expected response. The height of the cylinder may, for example, represent the performance index of the generator.

The functionality offered for monitoring, tracking and predicting the response performance to A.S. markets (hourly and daily) may, once again, be similar to the one of the previous two applications. Each supplier is represented by two color-coded pies and a cylinder. The pie represents the most recent response for the day ahead and hour ahead bids and the bids made by the suppliers in the A.S. markets. The cylinder height represents, as before, the performance index.

FIG. **33** illustrates a geographic-graphic visualization overview **440** of a control area and suppliers performance monitoring and prediction platform for AGC, FRR and regulation A.S. in an exemplary embodiment according to the present invention. As shown in FIG. **33**, the CAISO System operator will have available displays to monitor for the current time, last 24-hours and last X-minutes (default 10-minutes) both their CA and the individual suppliers response performance, forecast and tracking performance of CAISO AGC, Frequency Response Reserves (FRR), and hourly and daily Regulation Ancillary Services markets. In addition, besides having CA and suppliers performances for each service, CAISO System operators will also have available an integrated window that will show continuously the CA and suppliers performance for all four services simultaneously, and replay capability for displays on either of the panels from the 3-panel displays.

This application of the power grid management system allows the CAISO System operators and management to identify via 3-panel displays the CA and suppliers performance for each service on geographical displays for current time, the last ten minutes on co-plot displays, and for the past 24-hours on image-displays and user selected suppliers predictive performance. The bottom of the 3-panel displays will be user selectable, to switch from tabular text window correlated with the data in the 3 panels, to optionally show to System operators in a continuous horizontally scrollable window, the performance indices for AGC, FRR and regulation ancillary services. The indices will replay continuously for a selectable period of time that will include the prediction period.

FIG. **34** is a screen shot **450** of a panel view for control area and suppliers performance for, AGC, FRR and A.S. in an exemplary embodiment according to the present invention. It can be seen in FIG. **34** that there are five tabs at the top-left corner. Each of them presents a 3-panel display with the main panel, showing in a 3D map, the selected suppliers performance for the service selected and the other two panels showing the selected suppliers performance for the other two services. The three tabs at the top-right present the window for username/password, interface for user enterable parameters, and the help displays. The help displays, for example, may be based on Microsoft® PowerPoint® presentations.

The map and the cylinder pie-charts in the main panel display from the 3-panel display in FIG. **34** shows the current response of each supplier, selected from categorical options from a RMB menu, to the service selected from the tab. The other two panels also show the performance of the selected generators for the other two services.

The center-bottom of the 3-panel displays is user selectable to switch from tabular text window correlated with the data in the 3 panels, to optionally show to System operators continuously in a horizontally scrollable window the performance indices for AGC, FRR and regulation ancillary services. The indices will replay continuously for a selectable period of time that includes the prediction period. The three windows at the left-bottom of the screen contain the date/time for the data being displayed, an option to hold the automatic data refresh, and a yellow window to indicate the current action taken by the user

FIG. **35** is a screen shot **460** of a panel view for control area and generator response to AGC in an exemplary embodiment according to the present invention. FIG. **35** shows the 3D map and cylindrical pie-charts in the main panel display from the 3-panel display representing the current response of each generator, selected from categorical options from an RMB menu, to AGC, with the cylinder-height representing each generator performance index. The color of the CAISO control area may represent the response to AGC of all the suppliers providing the control area, represented by the performance indices previously discussed herein.

The image on the top-right panel shows the performance tracking of each of the suppliers online, selected from the RMB option, and may be color coded for the last 24-hours. The plot on the bottom-right panel shows the predictive plot. This plot includes a multi-series, time-based, linear chart. One series represents the recorded values of a variable over time and the second represents the predicted value for the same variable over the time period and for X additional predicted values. The plot also includes a vertical reference-line indicating the current time, relative to the time period being displayed. Multiple instances of this plot are used in the display, as illustrated, and the user selects the values for display via an options dialog.

The center-bottom of the 3-panel displays will be user selectable to switch from tabular text window correlated with the data in the 3 panels, to optionally show to system operators continuously in a horizontally scrollable window the performance indices for AGC, FRR and regulation ancillary services. The indices will replay continuously for a selectable period of time and will include the prediction period.

The three windows at the left-bottom of the screen contain the date/time for the data being displayed, an option to hold the automatic data refresh, and a yellow-window to indicate the current action taken by the user.

The two main windows at the right-bottom of the screen contain the navigation buttons that must be implemented as shown, and the replay bottoms that also must be implemented as shown.

The three tabs at the top-right present the window for username/password, windows for user enterable parameters, and the help displays based on Microsoft® PowerPoint® presentations.

FIG. **36** is a screen shot **470** for a panel view for control area and generators response to frequency response in an exemplary embodiment according to the present invention. FIG. **39** above shows the CAISO geographic map and color coded cylindrical pies placed at the geographic location of each

selected generator, with part of the pie representing the generator latest FRR response, the other part its expected FRR value and the last part the difference between actual and expected response. The height of the cylinder represents the FRR performance index for each selected generator.

The plot on the top-right panel shows the FRR performance tracking of each of the generators online, selected from the RMB option during the most recent frequency disturbances. The plot on the bottom-right shows the current selected generators FRR performance together with its performance variance for the hour, and the value predicted for the next excursion.

FIG. **37** is a screen shot **480** for a panel view for control area and generators response to regulation A.S. in an exemplary embodiment according to the present invention. FIG. **40** shows the CAISO geographic map and two concentric circles located at the geographic location of each selected generator, with the inner most circle representing the generator actual response for both the day-ahead and hour-ahead bids, and the outer most circle representing its Ancillary Service (both day-ahead and hourly-ahead) scheduled values. The height of the cylinder represents the Ancillary Services (day-ahead and hour ahead) performance indices for each selected generator.

The image on the top-right panel shows the Supplier Control Performance System (SCPS) for each of the generators selected, color-coded for the last X-Minutes (default 10-minutes). The plot on the bottom-right panel shows the predictive plot. This plot consists of a multi-series, time-based, linear chart. One series represents the recorded values of a variable over time and the second represents the predicted value for the same variable over the time period and for X additional predicted values. The plot also includes a vertical reference-line indicating the current time, relative to the time period being displayed. Multiple instances of this plot are used in the display, as illustrated, and the user selects the values for display via an options dialog.

FIG. **38** is a screen shot **490** of a common view for performance of AGC, FRR and X-Minutes Ancillary Services Regulation (Default 10-Minutes) in an exemplary embodiment according to the present invention. The format of FIG. **38** is equivalent for all three services using the corresponding performance data and indices. The main-panel shows the condition plot. It is similar to a scatter plot, created using the variables of one of the three services, the parameters of one of the three services and the names of the selected generators for a configurable, 10 minute time period (at 1 minute sampling frequency).

The following describes how the chart should be created as shown in FIG. **38** in an exemplary embodiment according to the present invention:

1) Run the appropriate database stored procedure.

2) Determine from the user interface the value to perform grouping, by performance, parameter or time.

3) Determine the unique grouping values.

4) Determine the median parameter value for each generator (using the whole dataset) and order the generator list by that value.

5) Create a scatter plot for each unique grouping value, with the data value plotted on the X-axis. Each scatter point is colored according to a color map defined in a configuration file (Red/Yellow/Green).

6) The scatter plots will be arranged on a grid by increasing value, left to right, top to bottom.

The image on the top-right panel shows the performance index for each generator selected, color-coded for the last X-Minutes (default 10-minutes). The cave-plot at the bottom-right shows at the top the response MW of any generator selected from the image-plot, and at the bottom the scheduled MW for the selected generator.

It will be appreciated by those of ordinary skill in the art that the invention can be embodied in other specific forms without departing from the spirit or essential character thereof. The present invention is therefore considered in all respects to be illustrative and not restrictive. The scope of the present invention is indicated by the appended claims, and all changes that come within the meaning and range of equivalents thereof are intended to be embraced therein.

What is claimed is:

1. A wide-area real-time performance monitoring system for monitoring and assessing dynamic stability of an electric power grid, the system comprising:

a monitor computer including an interface for receiving a plurality of data streams, each data stream comprising sub-second, time stamped synchronized phasor measurements wherein the measurements in each stream are collected at geographically distinct points over a wide area of the grid;

wherein the monitor computer monitors metrics including at least one of reliability metrics, power grid operations metrics, generation metrics, transmission metrics, suppliers metrics, grid infrastructure security metrics or market metrics over a wide area of the electric power grid, wherein the wide area comprises at least two distinct entities selected from the group consisting of transmission companies, utilities, and regional reliability coordinators;

wherein the monitor computer derives in real-time from the plurality of data streams from the at least two distinct entities selected from the group consisting of transmission companies, utilities, and regional reliability coordinators, one or more dynamic stability metrics including phase angles, damping, oscillation modes, and sensitivities for dynamics monitoring using phasor measurements in which the stability metrics are indicative of grid stress and/or instability, over the wide area; and

wherein the monitor computer is configured to supply at least two different categories of data concern the metrics to a graphical user interface coupled to the monitor computer for concurrently displaying the at least two different categories of data concerning the metrics,

wherein the categories of data include monitoring data, tracking data, historical data, prediction data, and summary data,

wherein the graphical user interface provides concurrent visualization of a plurality of metrics directed to a wide geographic area of the grid covering at least two distinct entities selected from the group consisting of transmission companies, utilities, and regional reliability coordinators, and

wherein the computer accumulates and updates wide area dynamic performance metrics in real time as to wide area and local area portions of the grid.

2. The performance monitoring system of claim **1**, wherein the monitor computer analyzes the monitored metrics and the graphical user interface displays results of analyzing the metrics.

3. The performance monitoring system of claim **2**, wherein the monitor computer determines whether any of the monitored metrics crosses a threshold anywhere within the wide area of the grid, identifies at least one of a utility company, transmission company, reliability entity or jurisdiction responsible for the local and/or wide portion of the electric power grid in which the threshold is crossed.

4. The performance monitoring system of claim **3**, wherein the determination by the monitor computer is transferred to another computer system for display, further analysis, or as an input for another calculation.

5. The performance monitoring system of claim **2**, wherein the monitor computer is configured to transfer the results of the analysis to another computer system for display, further analysis, or as an input for another calculation.

6. The performance monitoring system of claim **1**, wherein the monitor computer includes means for receiving data from remote locations.

7. The performance monitoring system of claim **1**, wherein the monitor computer is coupled to a global computer network for receiving data over the wide area and wherein the performance monitoring system can store the data and replay it for power grid system performance assessment, event diagnostics, root cause analysis of events and situational assessment of dynamic stability of the electric power grid in real time.

8. The performance monitoring system of claim **1**, wherein the monitor computer includes an application for performing real-time monitoring of at least one of voltage/VAR (volt-ampere reactive), ACE (area control error)-frequency, or AIE (area interchange error) schedule.

9. The performance monitoring system of claim **1**, wherein the monitor computer includes an application for performing real-time monitoring with data comprising at least one of supervisory control and data acquisition (SCADA), energy management system (EMS), or phasor measurements.

10. The performance monitoring system of claim **1**, wherein the wide area includes a geographic area comprising one or more cities, counties, states or countries.

11. The performance monitoring system of claim **1**, wherein the monitor computer includes means for enabling a user to drill down and visualize the data displayed on the graphical user interface at various geographical resolutions ranging from wide-area to local-area.

12. The performance monitoring system of claim **1**, wherein the monitor computer activates an alarm when a performance abnormality is detected in at least one metric of the monitored metrics.

13. The performance monitoring system of claim **1**, wherein the monitor computer includes means for notifying personnel when one or more of the metrics crosses a threshold.

14. The performance monitoring system of claim **13**, wherein the notifying of personnel occurs by e-mail, text message, pager, audible alarms, or visual displays.

15. The performance monitoring system of claim **1**, wherein the monitor computer includes a market monitoring application for performing real-time monitoring of the market metrics comprising at least one of market power, market price, price spikes, imbalance energy, demand forecast error, or safe regulation band.

16. The performance monitoring system of claim **15**, wherein the market monitoring application includes means for performing an action in response to one or more of the market metrics.

17. A method of performing wide area real time monitoring and assessment of dynamic stability of an electric power grid comprising:

receiving a plurality of data streams, each data stream comprising sub-second, time stamped synchronized phasor measurements wherein the measurements in each stream are collected at geographically distinct points over a wide area of the grid comprising at least two distinct entities selected from the group consisting of transmission companies, utility companies, and regional reliability coordinators;

monitoring dynamic stability metrics including phase angles, damping, oscillation modes, and sensitivities over the wide area of the electric power grid;

deriving in real-time from the plurality of data streams one or more stability metrics for dynamics monitoring using phasor measurements which are indicative of grid stress and/or instability;

updating the monitored metrics in real time;

concurrently displaying in graphical form at least two different categories of data concerning the metrics, wherein the categories are selected from a group consisting of monitoring data, tracking data, historical data, prediction data, and summary data;

updating the displayed data in real time;

analyzing the displayed data;

providing summary information concerning real time performance of the electric power grid; and

storing the data in real time for replay and review to perform power grid system performance assessment, event diagnostics, root cause analysis of events and situational assessment of dynamic stability of the electric power grid in real time.

18. The method of claim **17** further comprising identifying monitored data of a portion of the electric power grid that crosses a threshold.

19. The method of claim **18** further comprising alerting at least one of an operator or reliability coordinator responsible for the portion of the electric power grid in which the threshold is crossed.

20. The method of claim **19**, wherein the alert is delivered by e-mail, text message, pager, audible alarms, or visual displays.

21. The method of claim **17**, further comprising drilling down or zooming in and viewing data across the metrics and across the geographically distinct points.

22. A wide area real-time dynamics monitoring system for assessing dynamic stability of an electric power grid, the system comprising:

a monitor computer for receiving a plurality of data streams, each data stream comprising sub-second, time stamped synchronized phasor measurements wherein the measurements in each stream are collected at geographically distinct points over a wide area of the grid, the plurality of data streams being received by the monitor computer from third party utilities or transmission companies that provide the data, wherein the wide area comprises at least two distinct entities selected from the group consisting of transmission companies, utilities, and regional reliability coordinators,

wherein the monitor computer derives in real-time from the plurality of data streams from the at least two distinct entities one or more dynamic stability metrics including phase angles, damping, oscillation modes, and sensitivities for dynamics monitoring using phasor measurements in which the stability metrics are indicative of grid stress and instability, over the wide area, and

wherein the derived metrics include at least one of reactive reserve margin, power transfer angle, voltage/volt-ampere reactive (VAR), frequency response, sensitivities and/or combinations thereof;

a database to store the measurements and derived metrics; and

a display operatively coupled to the monitor computer and database for visualization of information relating to the plurality of the measurements and derived metrics rel-

evant to the assessment of the real-time dynamic stability of wide area and local area portions of the grid.

23. The wide area real-time dynamics monitoring system of claim **22**, wherein the monitor computer is adapted to enable an operator to monitor multiple control areas.

24. The wide area real-time dynamics monitoring system of claim **22**, wherein the monitor computer is adapted to enable an operator located in and responsible for monitoring a control area in one geographically distinct portion of the wide area to monitor one or more control areas in a separate geographically distinct portion of the wide area.

25. The wide area real-time dynamics monitoring system of claim **22**, wherein the monitor computer compares the derived metrics against operating limits.

26. The wide area real-time dynamics monitoring system of claim **22**, wherein the monitor computer compares the real time derived metrics with real time operating limits.

27. The wide area real time dynamics monitoring system of claim **26**, wherein the monitor computer is configured to compute the available margin between the real time operating limits and the current operating position, the available margin being calculated using at least one of a voltage margin, a real power margin, a reactive power margin, and a phase angle difference margin.

28. The wide area real-time dynamics monitoring system of claim **22**, further comprising threshold limits that are derived directly from observed statistical behavior of the monitored metrics to predict abnormal behavior within the electric power grid.

29. The wide area real-time dynamics monitoring system of claim **22**, wherein the monitor computer tracks one or more derived metrics for local or wide area in real-time based on a plurality of phasor measurements and performance metrics derived from phasor measurements.

30. The wide area real-time dynamics monitoring system of claim **29**, wherein the monitor computer enables an operator or reliability coordinator to develop a plan for action to respond to warning signs of grid emergencies.

31. The wide area real-time dynamics monitoring system of claim **30**, wherein the monitor computer notifies an operator or reliability coordinator of a utility, entity or jurisdiction when metric abnormalities are observed or limits are exceeded.

32. The wide area real-time dynamics monitoring system of claim **31**, wherein the monitor computer includes an application for monitoring a plurality of derived metrics, and wherein the application performs real-time monitoring of at least one of derived metrics from phasor measurements for the electric power grid or a portion thereof or for one or more of a plurality of control areas, wherein the electric power grid covers the wide area, the wide area extending across one or more cities, counties, states or countries.

33. The wide area real-time dynamics monitoring system of claim **22**, wherein the monitor computer includes visualization of metrics, including one or more of frequency response, voltage, or power angles.

34. The wide area real-time dynamics monitoring system of claim **22**, wherein the display of the derived metrics shows real-time tracking and trending of the derived metrics being monitored.

35. The wide area real-time dynamics monitoring system of claim **22**, wherein the monitor computer provides "what if" analysis.

36. The wide area real-time dynamics monitoring system of claim **22**, wherein the display concurrently displays at least one dynamic geographic display and a plurality of data or text panels.

37. The wide area real-time dynamics monitoring system of claim **22**, wherein the monitoring computer utilizes data from or is integrated with at least one of SCADA (Supervisory Control and Data Acquisition), EMS (Energy Management System), PMUs-PDCs (phasor measurement units-phasor data concentrators) or another control power system.

38. The wide area real-time dynamics monitoring system of claim **22**, wherein an operator of the monitor computer can define an application to monitor the derived metrics, which are related to the electric power grid at a local level, control area level, or regional level covering the wide area that the operator desires to monitor.

39. The wide area real-time dynamics monitoring system of claim **22**, wherein a display format of the information is customizable or configurable by an operator or a user.

40. The wide area real-time dynamics monitoring system of claim **22**, wherein the display is a monitor operatively coupled to the monitor computer.

41. The wide area real-time dynamics monitoring system of claim **22**, wherein the display is part of a display computer operatively coupled to the monitor computer.

42. The wide area real-time dynamics monitoring system of claim **41**, wherein the display computer is located in one of a plurality of control areas, transmission companies, utilities, or regional reliability coordinators or reliability jurisdictions and enables an operator in the one of the plurality of control areas to manage at least one grid portion corresponding to a different one of the plurality of control areas.

43. The wide area real-time dynamics monitoring system of claim **22**, wherein the monitor computer is a server and the display comprises a client in a server-client architecture.

44. The wide area real-time dynamics monitoring system of claim **22**, wherein the monitor computer is a dedicated server.

45. The wide area real-time dynamics monitoring system of claim **22**, wherein the monitor computer and the display communicate with each other in on of a web environment or over a secure proprietary network.

46. The wide area real-time dynamics monitoring system of claim **22**, wherein an operator viewing the display can interactively collect historical data and view a visualization of the historical data in a tabular, graphical or a customized format.

47. The wide area real-time dynamics monitoring system of claim **22**, wherein the operator viewing the display can create interactive data reports from the metrics stored in a database.

48. The wide area real-time dynamics monitoring system of claim **22**, wherein the monitor computer monitors proximity to thresholds, and the display graphically represents the proximity to thresholds or limits.

49. The wide area real-time dynamics monitoring system of claim **22**, wherein the monitor computer tracks, identifies and saves data on defined or abnormal operating conditions in a database, and the display provides visualization of the abnormal operating conditions.

50. The wide area real-time dynamics monitoring system of claim **22**, wherein the monitor computer in one of a plurality of control areas enables wide area real-time control of the grid.

51. The wide area real-time dynamics monitoring system of claim **22**, wherein the monitor computer performs wide area monitoring of the electric power grid using at least one of SCADA (Supervisory Control and Data Acquisition) data and/or time synchronized data from phasors or other sources.

52. The real-time performance monitoring system of claim **22**, wherein the monitor computer receives data concerning

reliability metrics, electric power grid operations metrics, generation metrics, transmission metrics, suppliers metrics, grid infrastructure security metrics or markets metrics for the electric power grid are monitored across a wide area covering multiple control areas and utilities; wherein each of a plurality of grid portions includes a network of high voltage transmission lines and generators interconnected to the network that is spread out over the multiple control areas across the wide area; wherein the plurality of grid portions are subject to power blackouts that spread or cascade over the wide area; and wherein an operator using the monitor computer is a reliability coordinator having responsibility to monitor the derived metrics over the wide area for reliability management; and

prevent power blackouts that spread or cascade over the wide area.

53. The wide area real-time dynamics monitoring system of claim **22**, wherein the monitor computer is configured to store the data in real time for replay and review to perform power grid system performance assessment, event diagnostics, root cause analysis of events and situational assessment of dynamic stability of the electric power grid in real time.

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(54) **WIDE-AREA, REAL-TIME MONITORING AND VISUALIZATION SYSTEM**

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See application file for complete search history.

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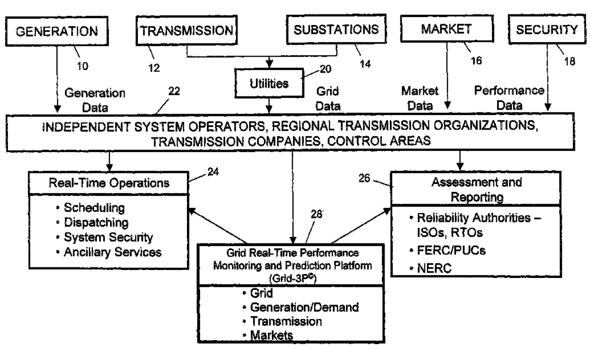
(57) **ABSTRACT**

A real-time performance monitoring system for monitoring an electric power grid. The electric power grid has a plurality of grid portions, each grid portion corresponding to one of a plurality of control areas. The real-time performance monitoring system includes a monitor computer for monitoring at least one of reliability metrics, generation metrics, transmission metrics, suppliers metrics, grid infrastructure security metrics, and markets metrics for the electric power grid. The data for metrics being monitored by the monitor computer are stored in a data base, and a visualization of the metrics is displayed on at least one display computer having a monitor. The at least one display computer in one said control area enables an operator to monitor the grid portion corresponding to a different said control area.

22 Claims, 41 Drawing Sheets



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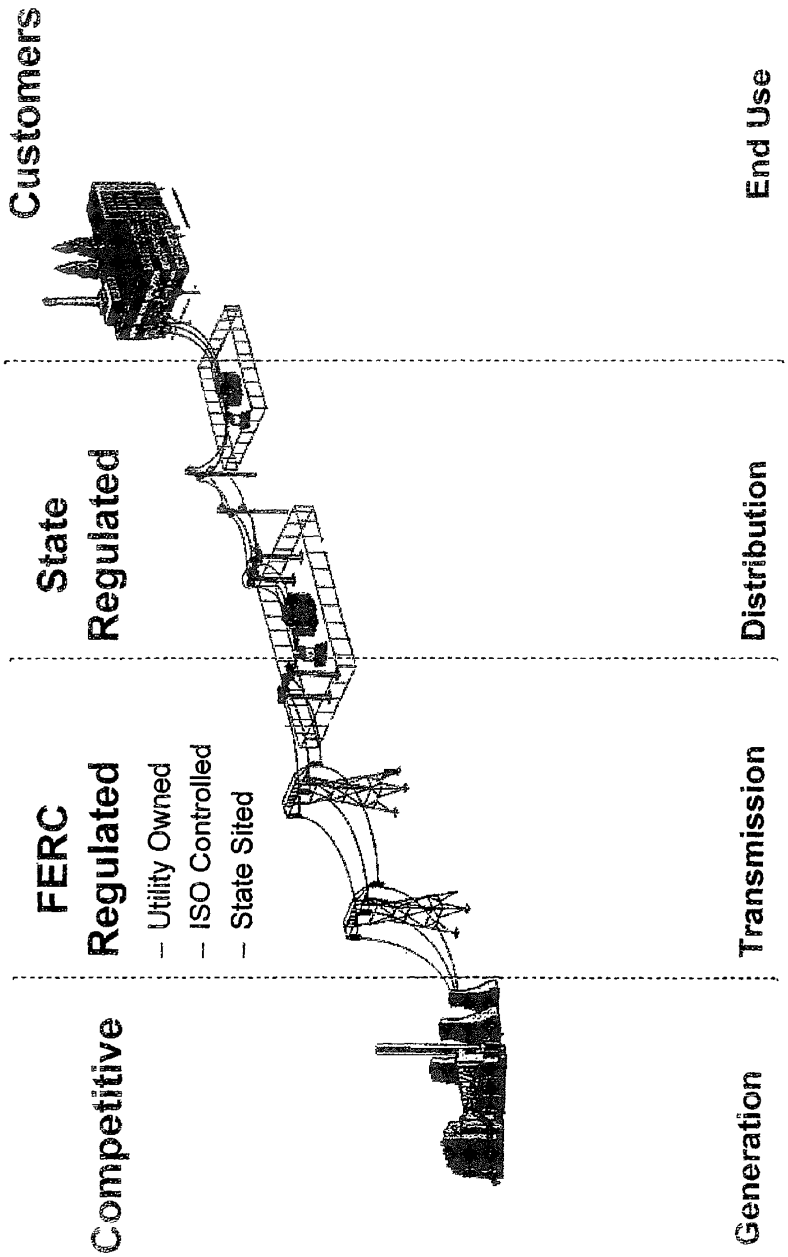


FIG. 1A
PRIOR ART

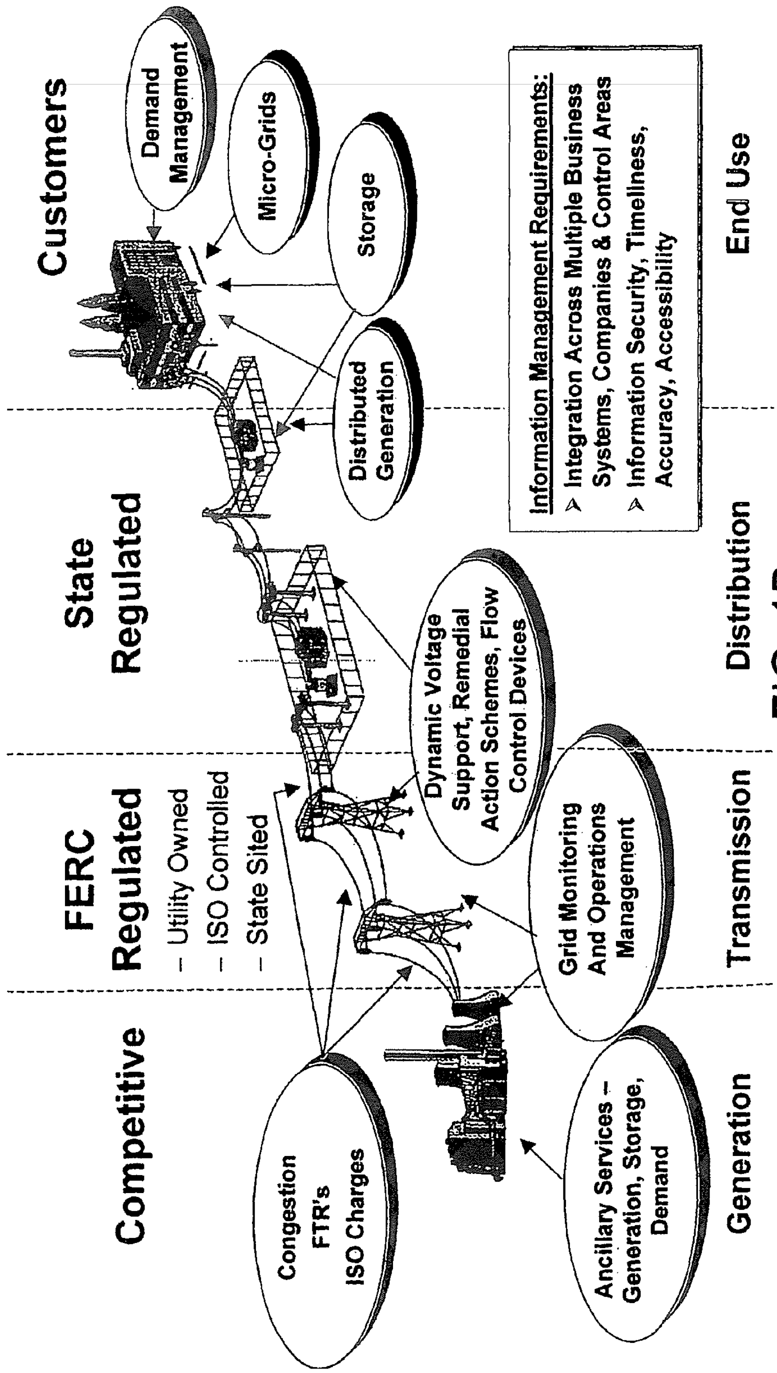

Competitive
FERC Regulated
– Utility Owned
– ISO Controlled
– State Sited
State Regulated
Customers
Congestion
FTR's
ISO Charges
Ancillary Services – Generation, Storage, Demand
Grid Monitoring And Operations Management
Dynamic Voltage Support, Remedial Action Schemes, Flow Control Devices
Distributed Generation
Storage
Micro-Grids
Demand Management
Information Management Requirements:
➢ Integration Across Multiple Business Systems, Companies & Control Areas
➢ Information Security, Timeliness, Accuracy, Accessibility
Generation
Transmission
Distribution
End Use

FIG. 1B

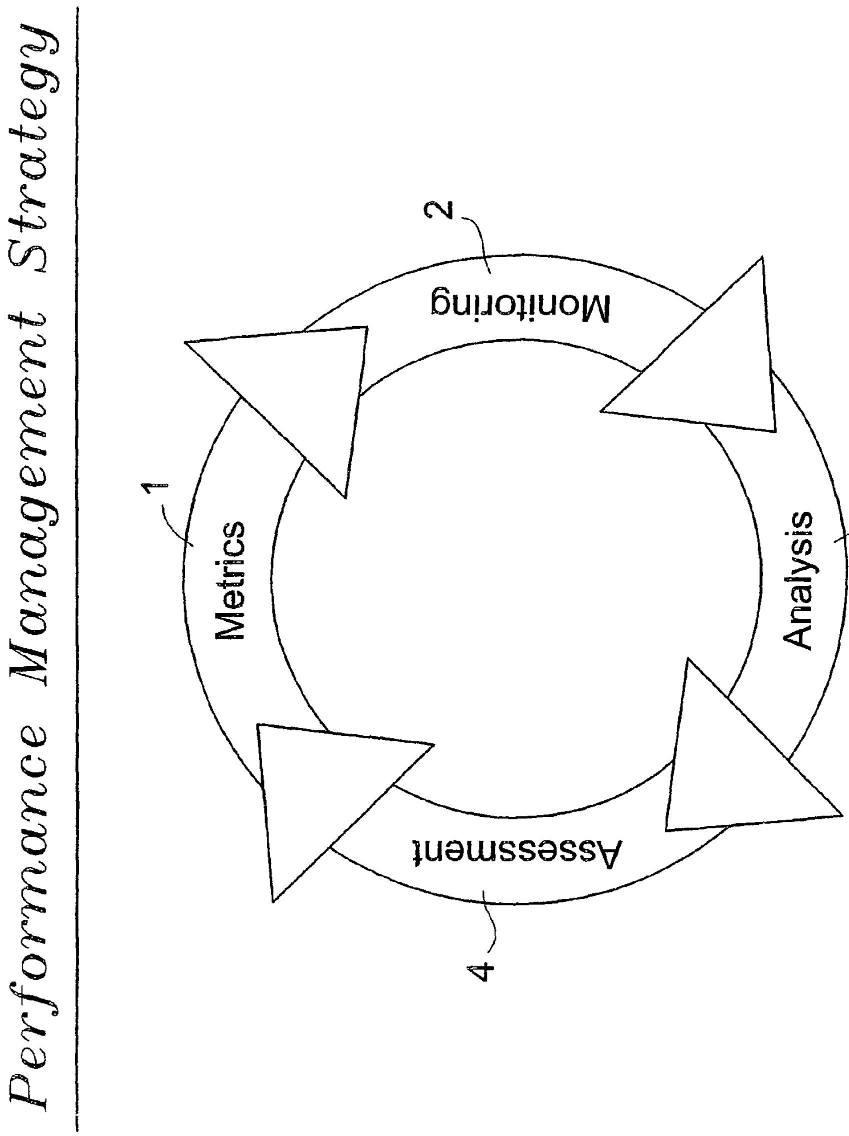

Performance Management Strategy
Metrics
Monitoring
Analysis
Assessment
1
2
3
4

FIG. 2A

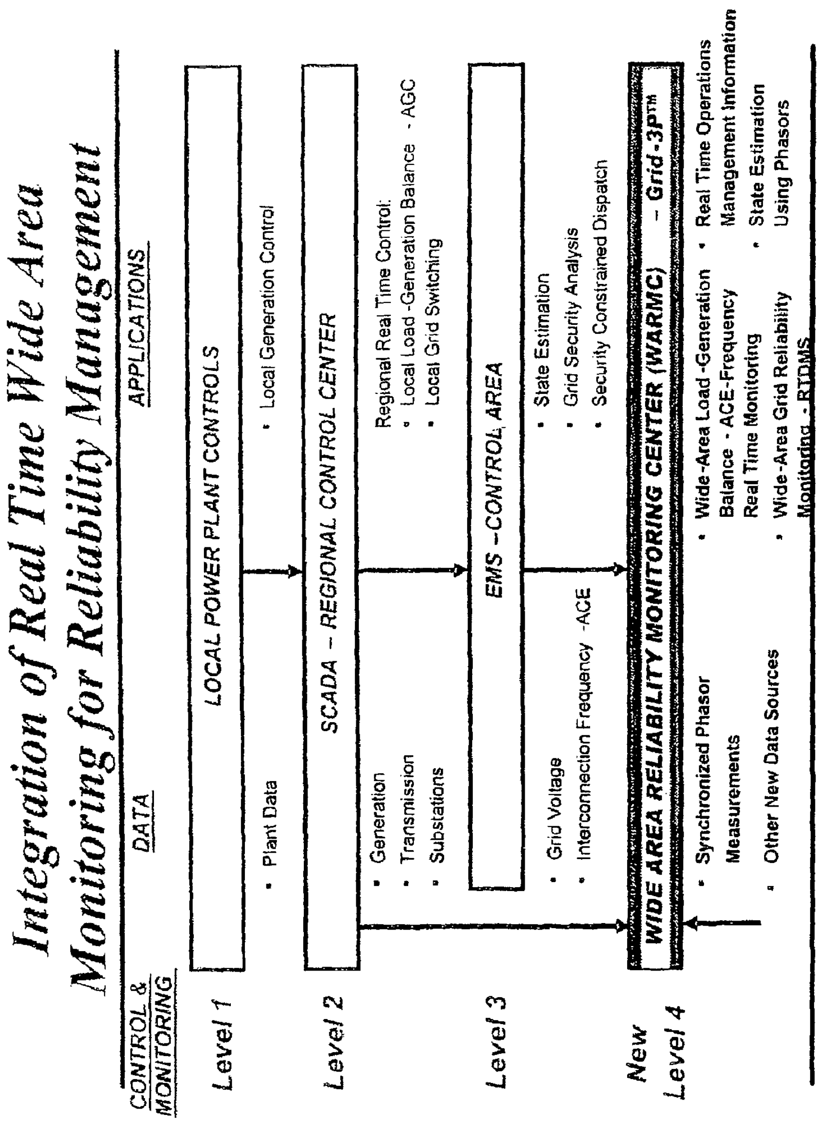

Integration of Real Time Wide Area Monitoring for Reliability Management
CONTROL & MONITORING
DATA
APPLICATIONS
Level 1
LOCAL POWER PLANT CONTROLS
• Plant Data
• Local Generation Control
Level 2
SCADA – REGIONAL CONTROL CENTER
• Generation
• Transmission
• Substations
Regional Real Time Control:
• Local Load -Generation Balance - AGC
• Local Grid Switching
Level 3
EMS –CONTROL AREA
• Grid Voltage
• Interconnection Frequency -ACE
• State Estimation
• Grid Security Analysis
• Security Constrained Dispatch
New Level 4
WIDE AREA RELIABILITY MONITORING CENTER (WARMC) – Grid-3P™
• Synchronized Phasor Measurements
• Other New Data Sources
• Wide-Area Load -Generation Balance - ACE-Frequency Real Time Monitoring
• Wide-Area Grid Reliability Monitoring - RTDMS
• Real Time Operations Management Information
• State Estimation Using Phasors

FIG. 2B

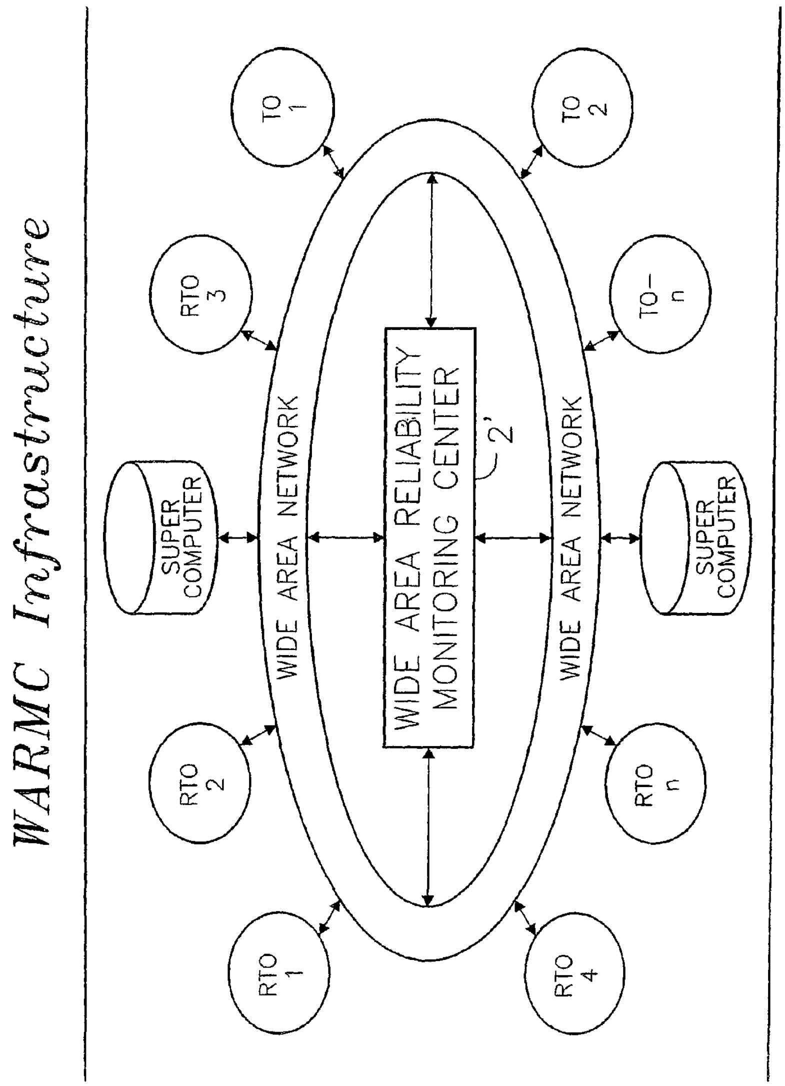

WARMC Infrastructure
TO 1
TO 2
RTO 3
TO-n
SUPER COMPUTER
SUPER COMPUTER
WIDE AREA NETWORK
WIDE AREA NETWORK
WIDE AREA RELIABILITY MONITORING CENTER
2'
RTO 2
RTO n
RTO 1
RTO 4

FIG. 2C

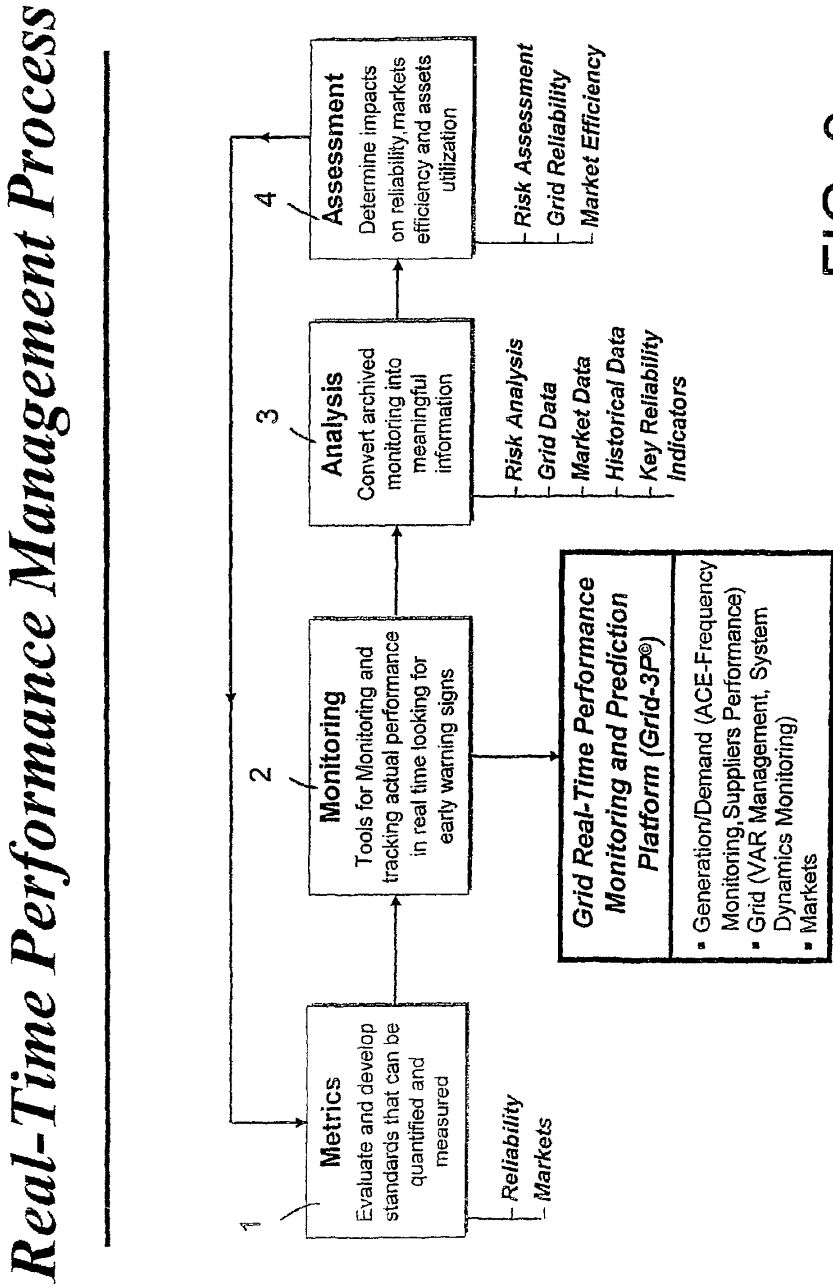

Real-Time Performance Management Process
1
Metrics
Evaluate and develop standards that can be quantified and measured
Reliability
Markets
2
Monitoring
Tools for Monitoring and tracking actual performance in real time looking for early warning signs
3
Analysis
Convert archived monitoring into meaningful information
Risk Analysis
Grid Data
Market Data
Historical Data
Key Reliability Indicators
4
Assessment
Determine impacts on reliability,markets efficiency and assets utilization
Risk Assessment
Grid Reliability
Market Efficiency
Grid Real-Time Performance Monitoring and Prediction Platform (Grid-3P©)
Generation/Demand (ACE-Frequency Monitoring,Suppliers Performance)
Grid (VAR Management, System Dynamics Monitoring)
Markets

FIG. 3

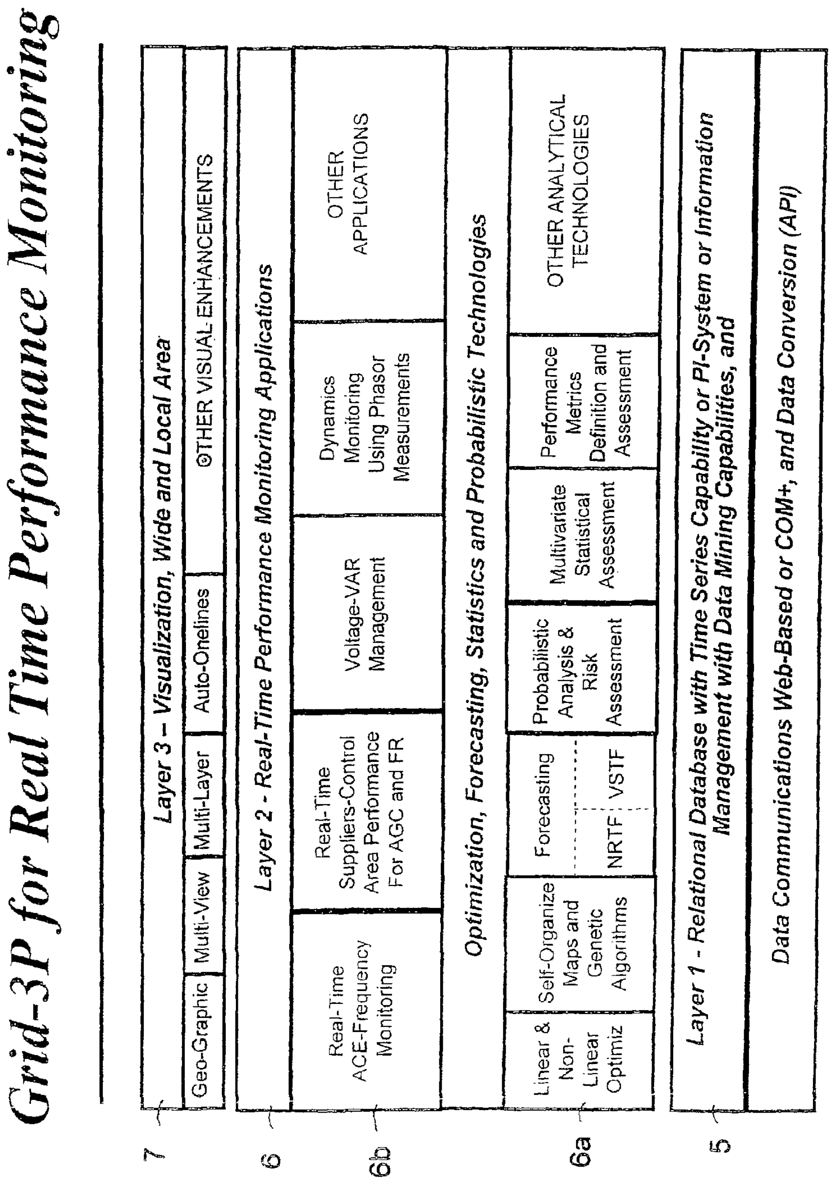

Grid-3P for Real Time Performance Monitoring
Layer 3 – Visualization, Wide and Local Area
Geo-Graphic
Multi-View
Multi-Layer
Auto-Onelines
OTHER VISUAL ENHANCEMENTS
Layer 2 - Real-Time Performance Monitoring Applications
Real-Time ACE-Frequency Monitoring
Real-Time Suppliers-Control Area Performance For AGC and FR
Voltage-VAR Management
Dynamics Monitoring Using Phasor Measurements
OTHER APPLICATIONS
Optimization, Forecasting, Statistics and Probabilistic Technologies
Linear & Non-Linear Optimiz
Self-Organize Maps and Genetic Algorithms
Forecasting
NRTF
VSTF
Probabilistic Analysis & Risk Assessment
Multivariate Statistical Assessment
Performance Metrics Definition and Assessment
OTHER ANALYTICAL TECHNOLOGIES
Layer 1 - Relational Database with Time Series Capability or PI-System or Information Management with Data Mining Capabilities, and
Data Communications Web-Based or COM+, and Data Conversion (API)
7
6
6b
6a
5

FIG. 4

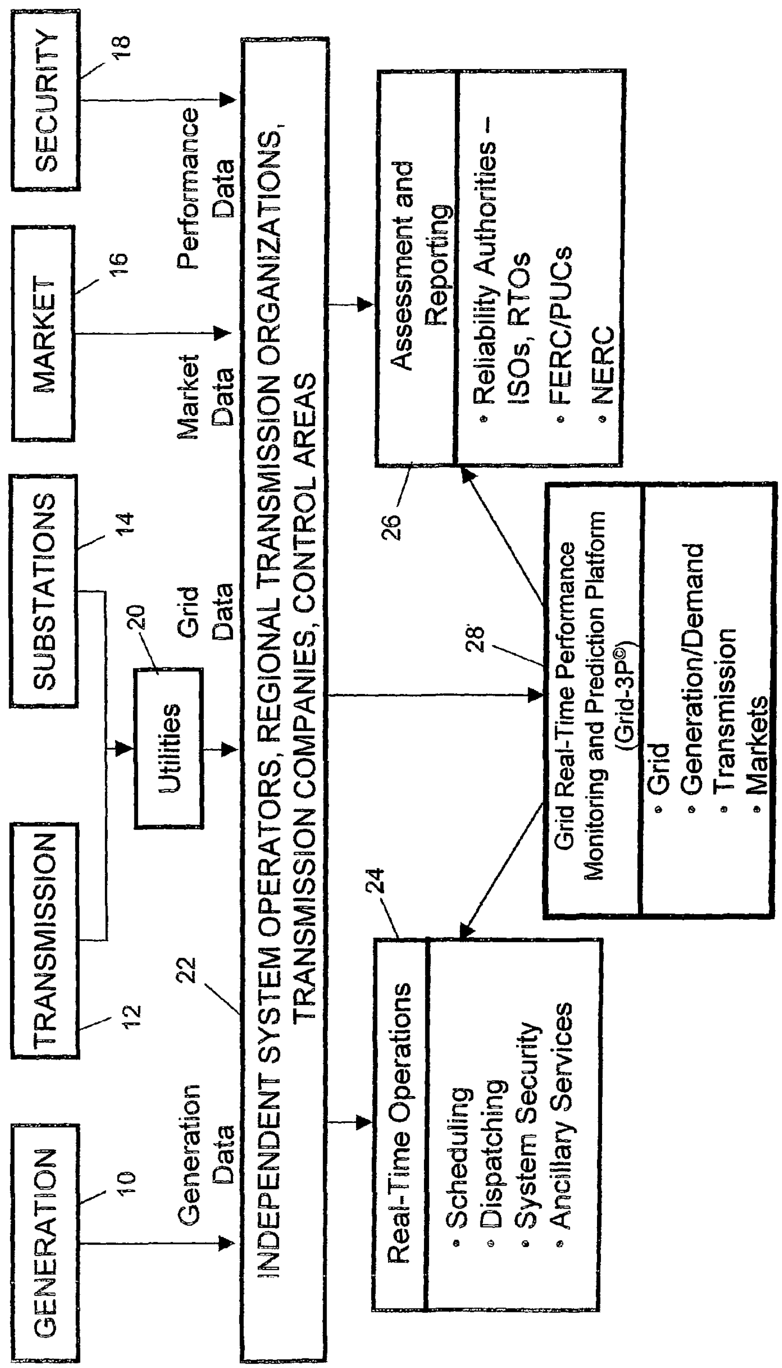

GENERATION
10
TRANSMISSION
12
SUBSTATIONS
14
MARKET
16
SECURITY
18
Utilities
20
Generation Data
22
Grid Data
Market Data
Performance Data
INDEPENDENT SYSTEM OPERATORS, REGIONAL TRANSMISSION ORGANIZATIONS, TRANSMISSION COMPANIES, CONTROL AREAS
Real-Time Operations
• Scheduling
• Dispatching
• System Security
• Ancillary Services
24
Grid Real-Time Performance Monitoring and Prediction Platform (Grid-3P©)
• Grid
• Generation/Demand
• Transmission
• Markets
28
Assessment and Reporting
• Reliability Authorities – ISOs, RTOs
• FERC/PUCs
• NERC
26

FIG. 5

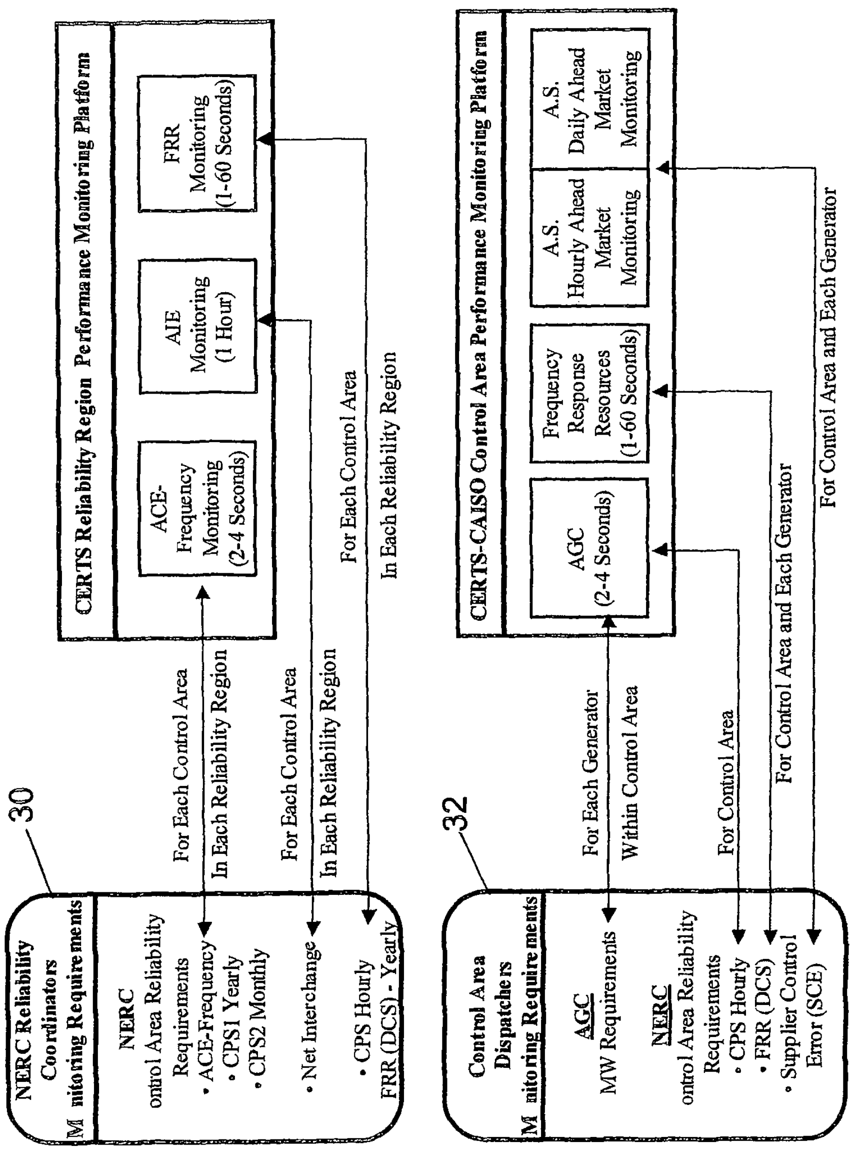

30
NERC Reliability Coordinators Monitoring Requirements
NERC Control Area Reliability Requirements
• ACE-Frequency
• CPS1 Yearly
• CPS2 Monthly
• Net Interchange
• CPS Hourly
FRR (DCS) - Yearly
For Each Control Area
In Each Reliability Region
For Each Control Area
In Each Reliability Region
For Each Control Area
In Each Reliability Region
CERTS Reliability Region Performance Monitoring Platform
ACE-Frequency Monitoring (2-4 Seconds)
AIE Monitoring (1 Hour)
FRR Monitoring (1-60 Seconds)
32
Control Area Dispatchers Monitoring Requirements
AGC
MW Requirements
NERC
Control Area Reliability Requirements
• CPS Hourly
• FRR (DCS)
• Supplier Control Error (SCE)
For Each Generator
Within Control Area
For Control Area
For Control Area and Each Generator
For Control Area and Each Generator
CERTS-CAISO Control Area Performance Monitoring Platform
AGC (2-4 Seconds)
Frequency Response Resources (1-60 Seconds)
A.S. Hourly Ahead Market Monitoring
A.S. Daily Ahead Market Monitoring

FIG. 6

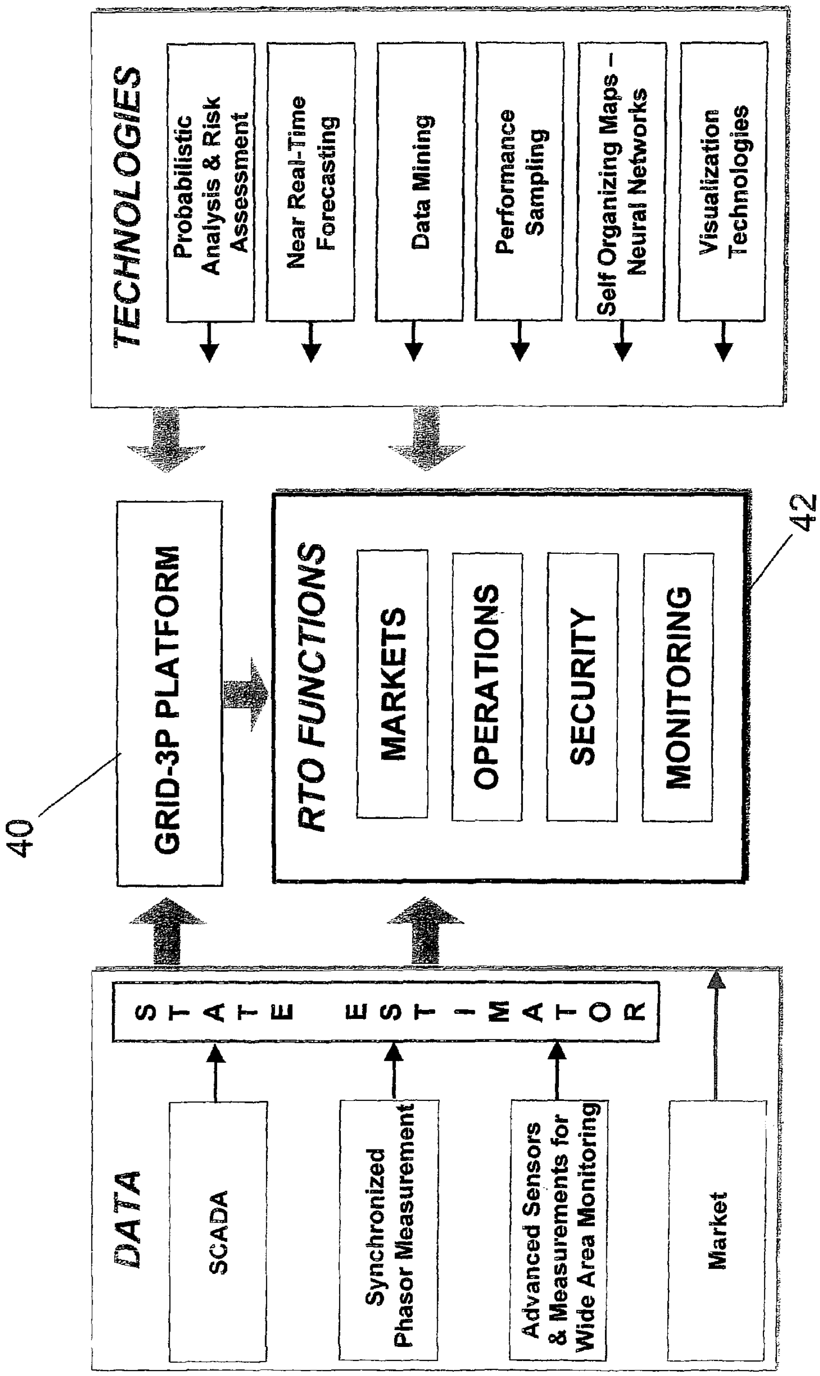

TECHNOLOGIES
Probabilistic Analysis & Risk Assessment
Near Real-Time Forecasting
Data Mining
Performance Sampling
Self Organizing Maps – Neural Networks
Visualization Technologies
GRID-3P PLATFORM
40
RTO FUNCTIONS
MARKETS
OPERATIONS
SECURITY
MONITORING
42
DATA
STATE ESTIMATOR
SCADA
Synchronized Phasor Measurement
Advanced Sensors & Measurements for Wide Area Monitoring
Market

FIG. 7

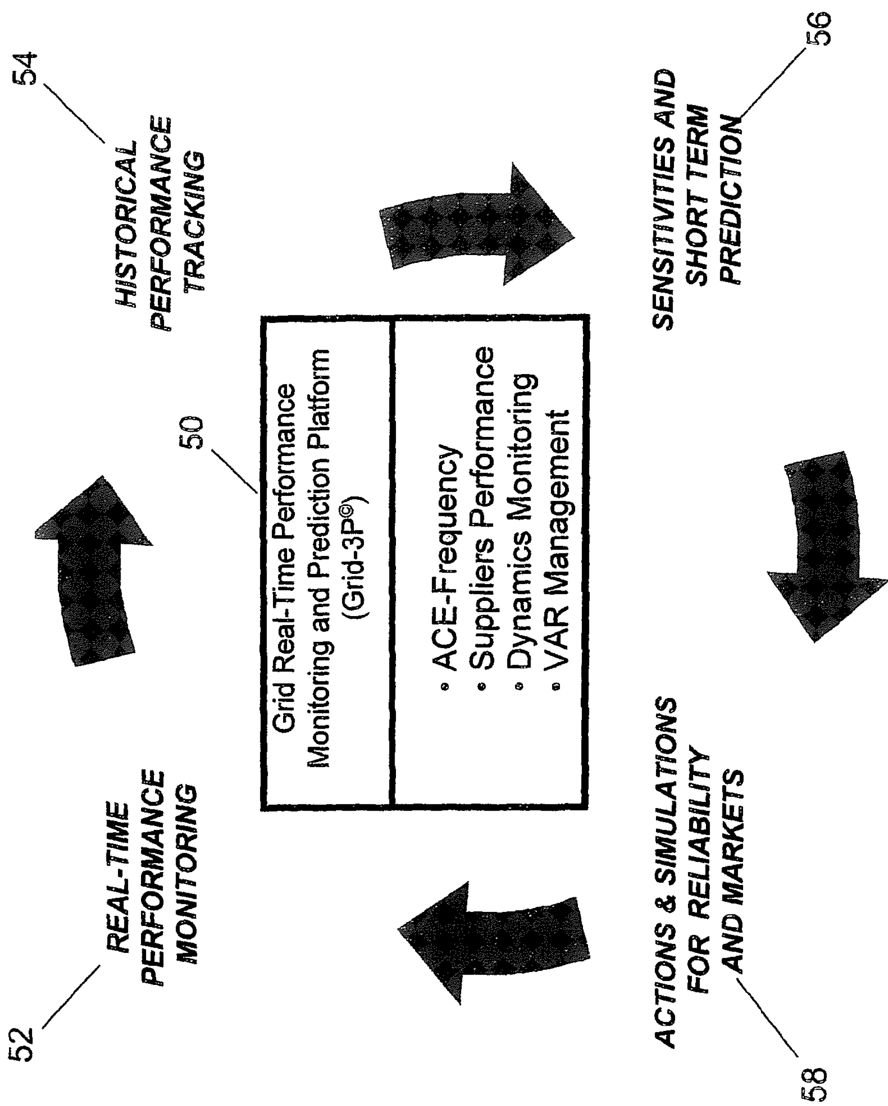
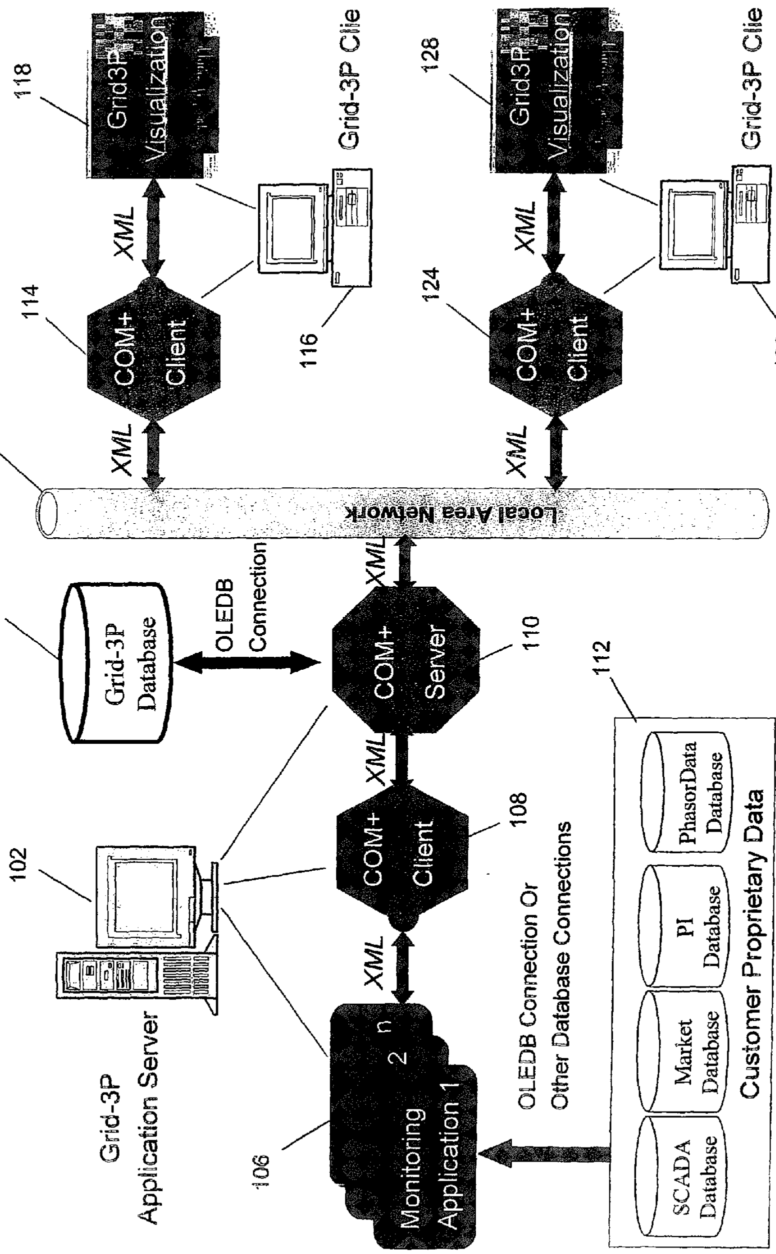

50
Grid Real-Time Performance Monitoring and Prediction Platform (Grid-3P©)
• ACE-Frequency
• Suppliers Performance
• Dynamics Monitoring
• VAR Management
52
REAL-TIME PERFORMANCE MONITORING
54
HISTORICAL PERFORMANCE TRACKING
56
SENSITIVITIES AND SHORT TERM PREDICTION
58
ACTIONS & SIMULATIONS FOR RELIABILITY AND MARKETS

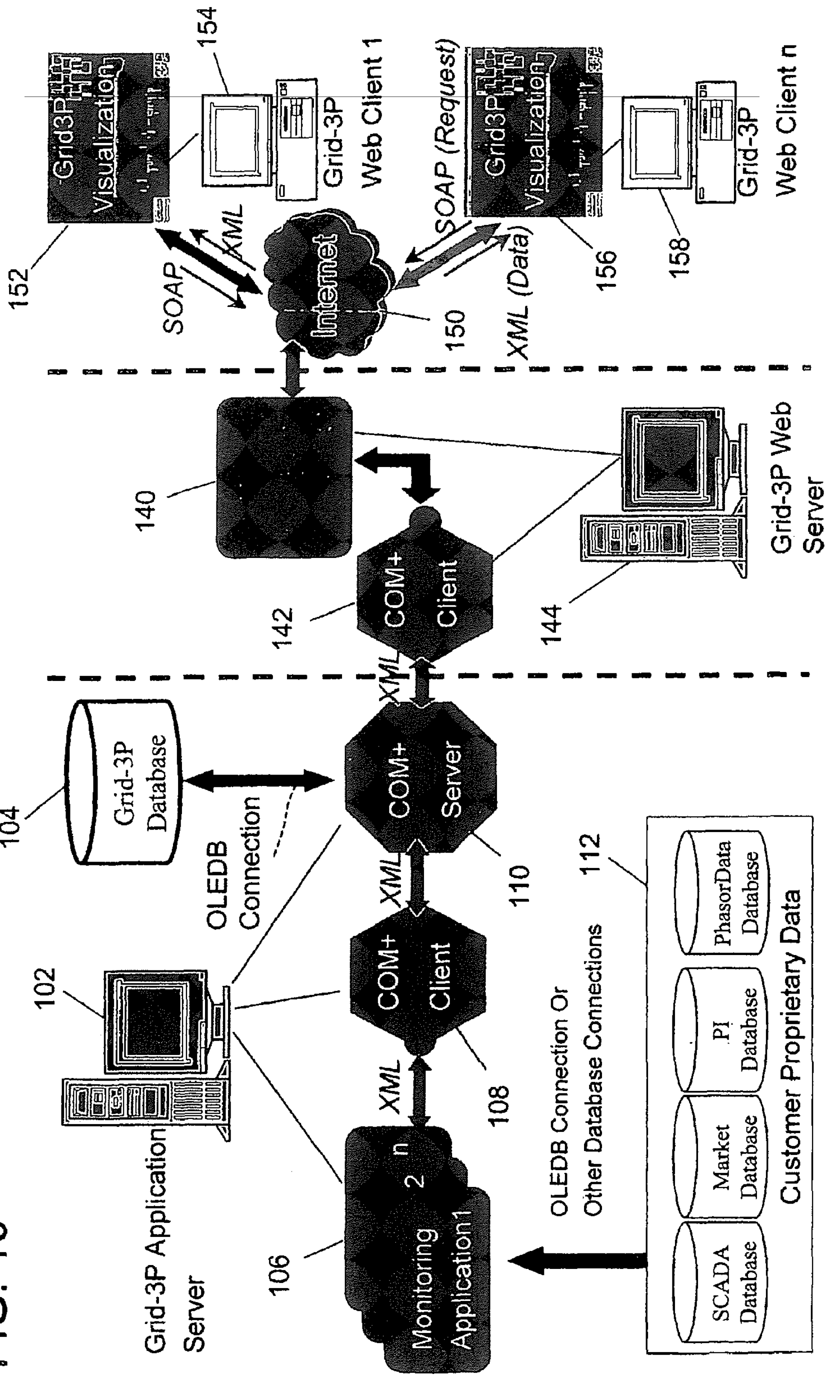
FIG. 8

FIG. 9



Grid3P Visualization
118
Grid-3P Clie
XML
COM+ Client
114
116
Grid3P Visualization
128
Grid-3P Clie
XML
COM+ Client
124
126
100
XML
Local Area Network
104
Grid-3P Database
OLEDB Connection
XML
COM+ Server
110
112
102
XML
COM+ Client
108
Grid-3P Application Server
XML
Monitoring Application 1
2
n
106
OLEDB Connection Or Other Database Connections
SCADA Database
Market Database
PI Database
PhasorData Database
Customer Proprietary Data

FIG. 10


Grid3P Visualization
152
Grid-3P Web Client 1
154
SOAP
XML
Internet
150
SOAP (Request)
XML (Data)
Grid3P Visualization
156
Grid-3P Web Client n
158
140
COM+ Client
142
Grid-3P Web Server
144
XML
Grid-3P Database
104
OLEDB Connection
COM+ Server
110
XML
COM+ Client
108
102
Grid-3P Application Server
XML
Monitoring Application1
2
n
106
OLEDB Connection Or Other Database Connections
112
SCADA Database
Market Database
PI Database
PhasorData Database
Customer Proprietary Data

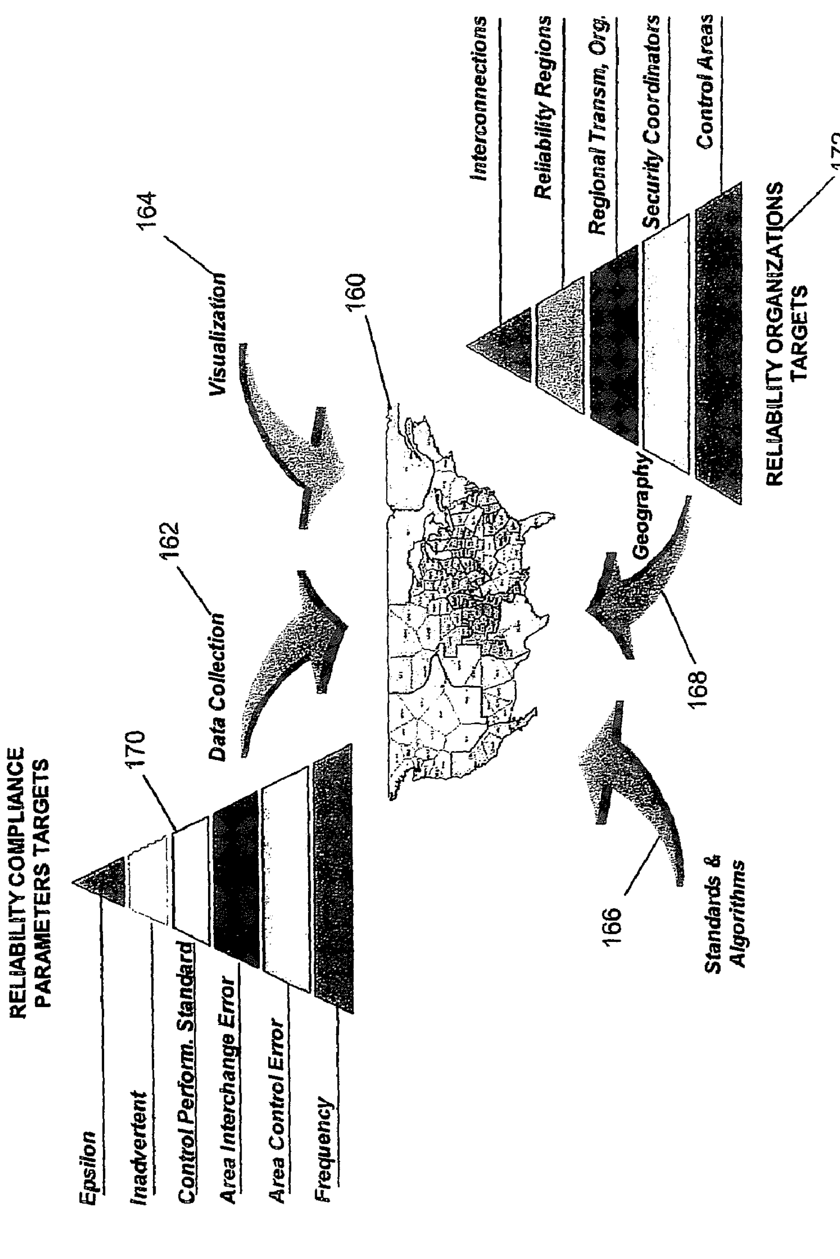

RELIABILITY COMPLIANCE PARAMETERS TARGETS
Epsilon
Inadvertent
Control Perform. Standard
Area Interchange Error
Area Control Error
Frequency
170
Data Collection
162
Visualization
164
160
Standards & Algorithms
166
Geography
168
Interconnections
Reliability Regions
Regional Transm. Org.
Security Coordinators
Control Areas
RELIABILITY ORGANIZATIONS TARGETS
172

FIG. 11

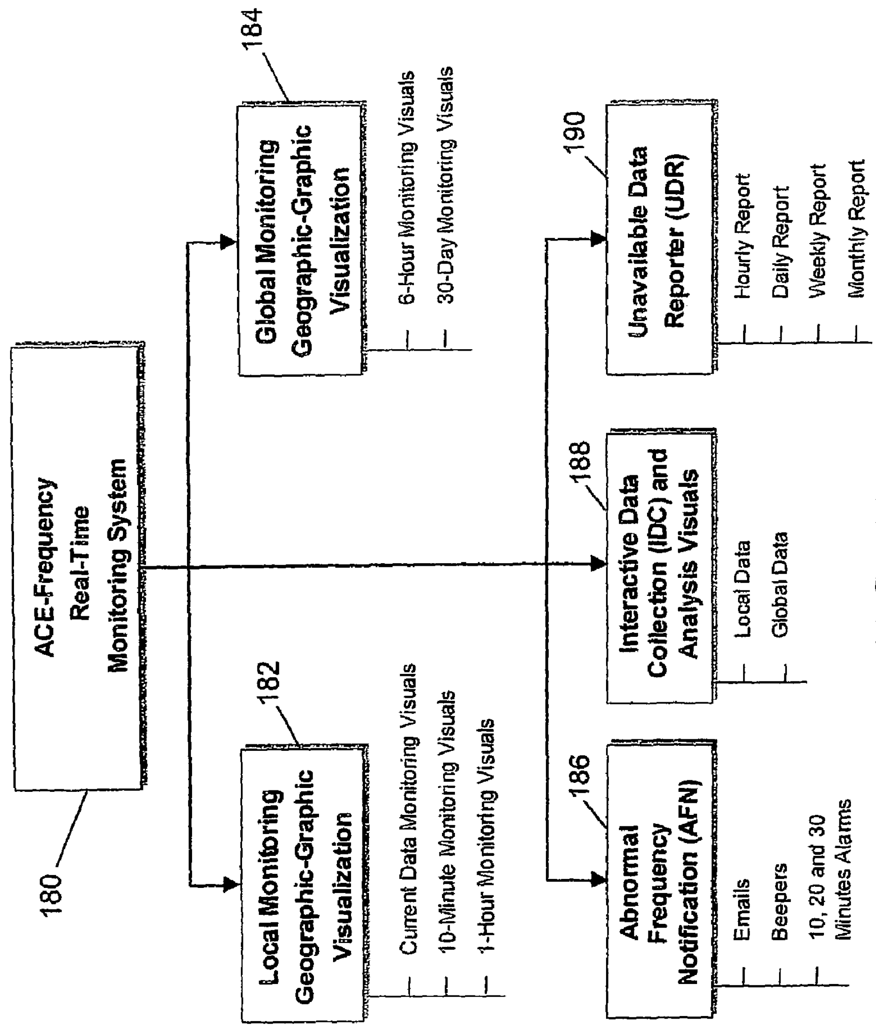
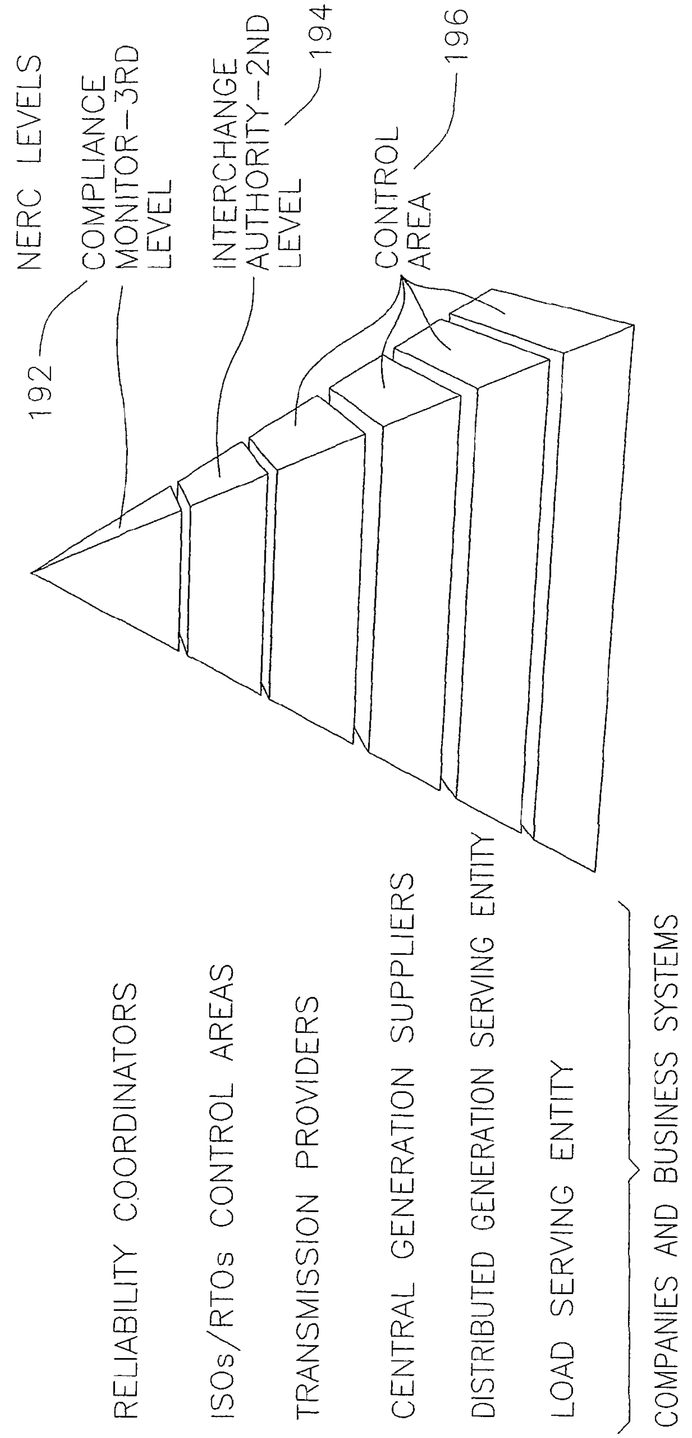

ACE-Frequency Real-Time Monitoring System
180
Local Monitoring Geographic-Graphic Visualization
182
Current Data Monitoring Visuals
10-Minute Monitoring Visuals
1-Hour Monitoring Visuals
Global Monitoring Geographic-Graphic Visualization
184
6-Hour Monitoring Visuals
30-Day Monitoring Visuals
Abnormal Frequency Notification (AFN)
186
Emails
Beepers
10, 20 and 30 Minutes Alarms
Interactive Data Collection (IDC) and Analysis Visuals
188
Local Data
Global Data
Unavailable Data Reporter (UDR)
190
Hourly Report
Daily Report
Weekly Report
Monthly Report

FIG. 12

FIG.13


NERC LEVELS
COMPLIANCE MONITOR−3RD LEVEL
INTERCHANGE AUTHORITY−2ND LEVEL
194
CONTROL AREA
196
192
RELIABILITY COORDINATORS
ISOs/RTOs CONTROL AREAS
TRANSMISSION PROVIDERS
CENTRAL GENERATION SUPPLIERS
DISTRIBUTED GENERATION SERVING ENTITY
LOAD SERVING ENTITY
COMPANIES AND BUSINESS SYSTEMS

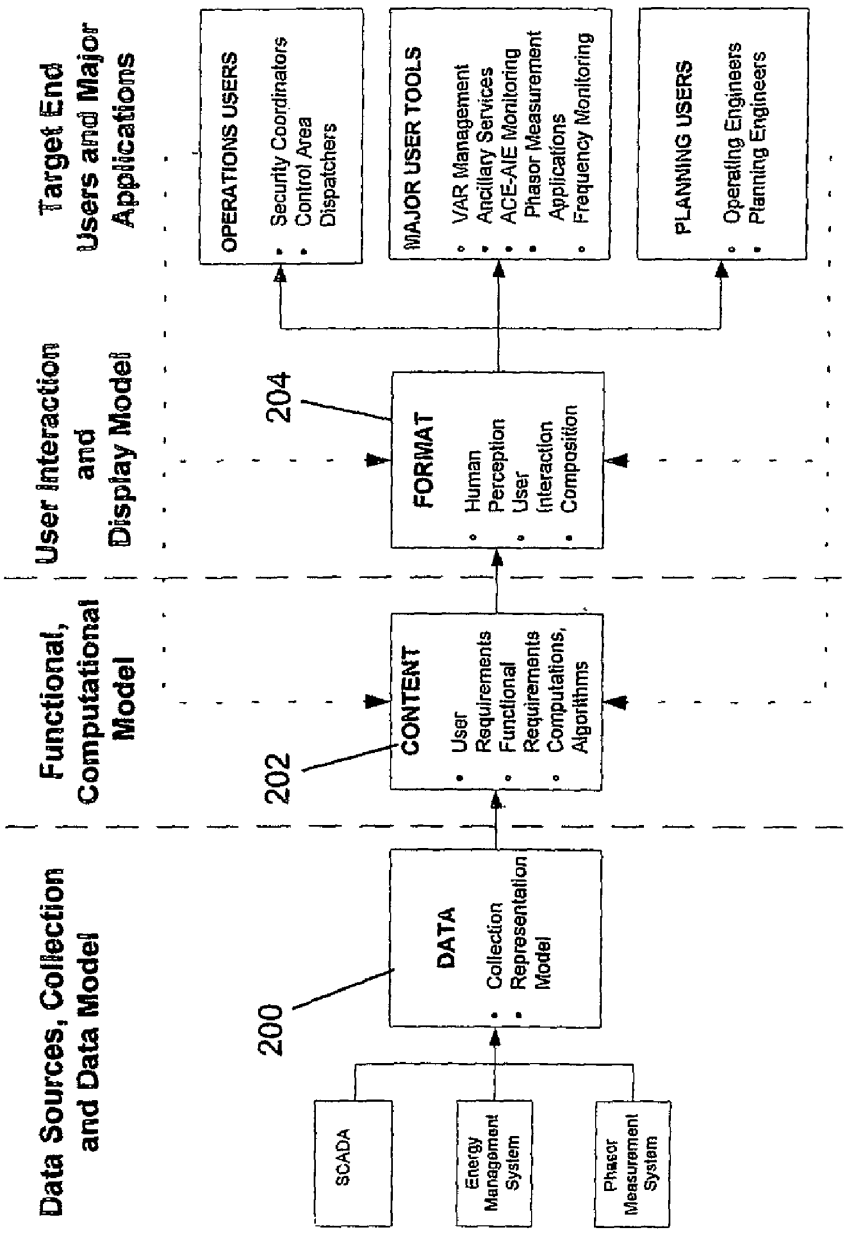

Data Sources, Collection and Data Model
Functional, Computational Model
User Interaction and Display Model
Target End Users and Major Applications
SCADA
Energy Management System
Phasor Measurement System
200
DATA
Collection
Representation Model
202
CONTENT
User Requirements
Functional Requirements
Computations, Algorithms
204
FORMAT
Human Perception
User Interaction
Composition
OPERATIONS USERS
Security Coordinators
Control Area Dispatchers
MAJOR USER TOOLS
VAR Management
Ancillary Services
ACE-AIE Monitoring
Phasor Measurement Applications
Frequency Monitoring
PLANNING USERS
Operating Engineers
Planning Engineers

FIG. 14

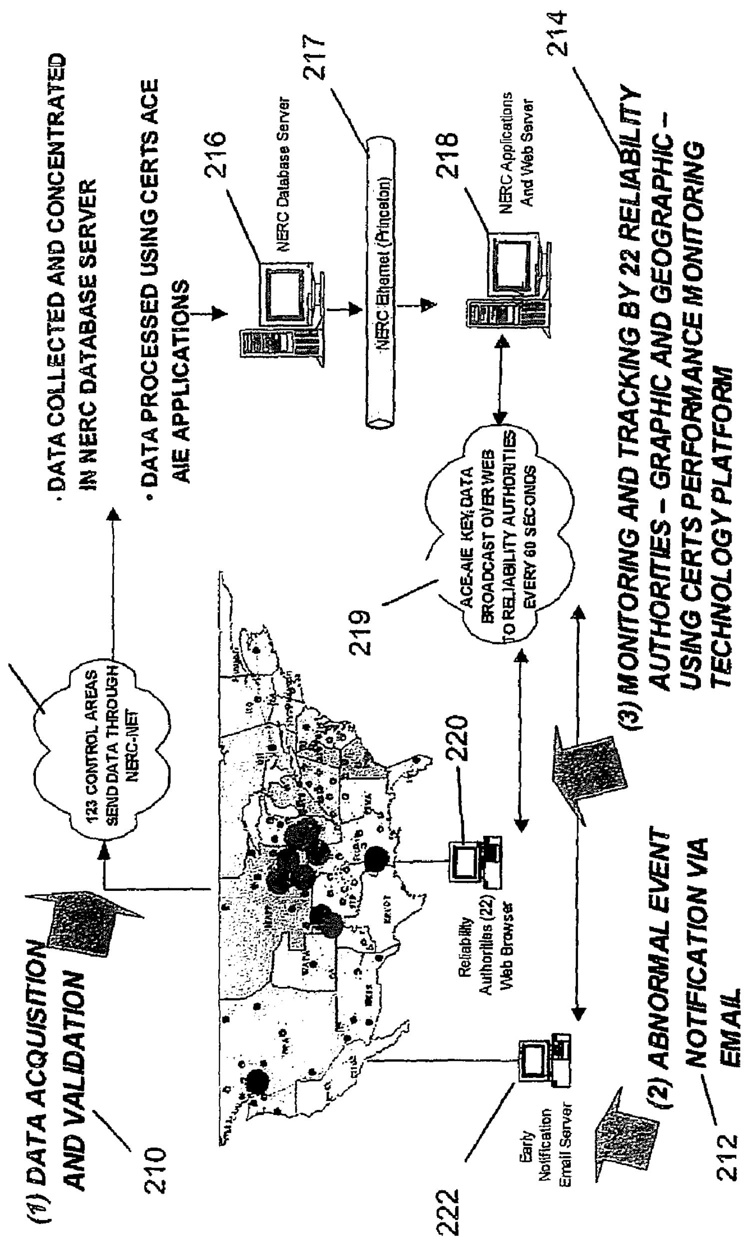
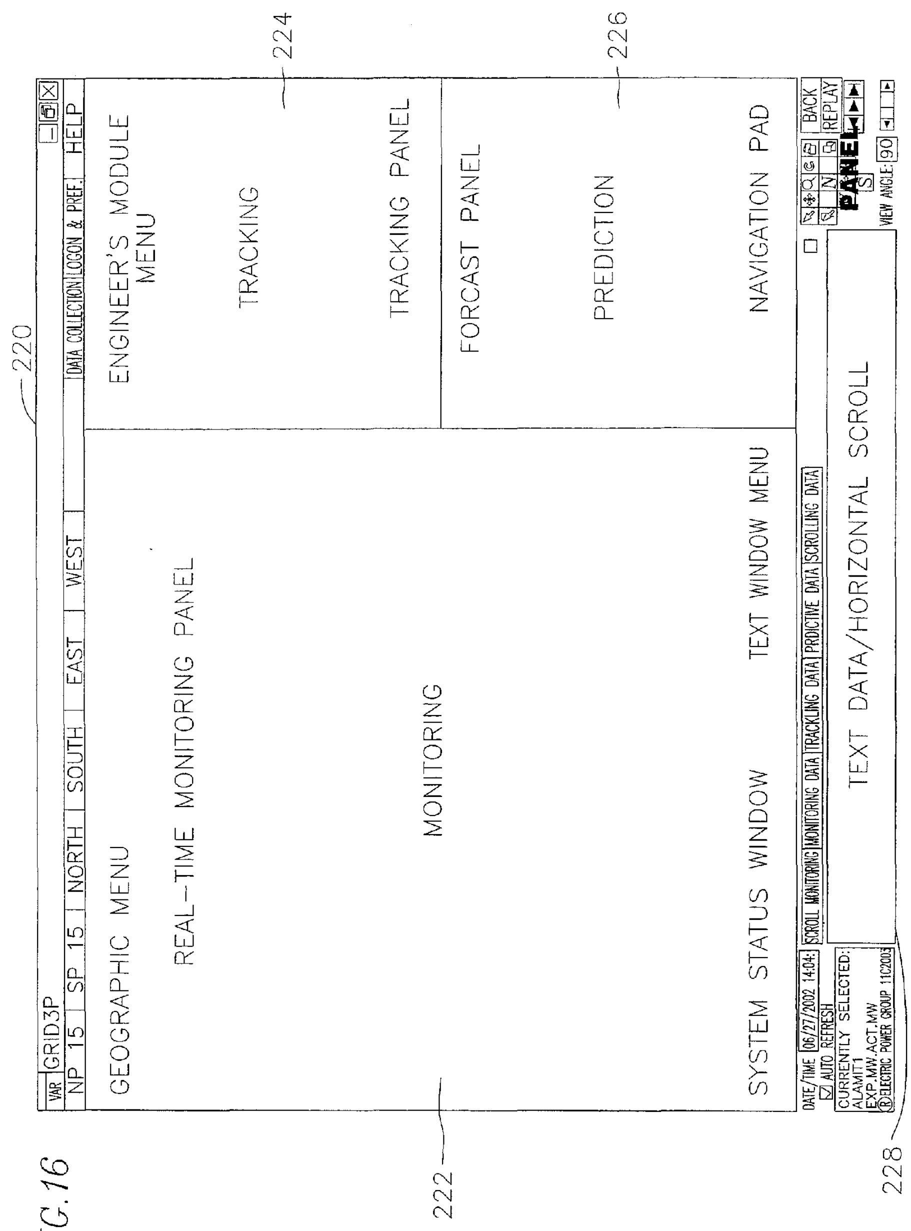

(1) DATA ACQUISITION AND VALIDATION
210
211
123 CONTROL AREAS SEND DATA THROUGH NERC-NET
· DATA COLLECTED AND CONCENTRATED IN NERC DATABASE SERVER
· DATA PROCESSED USING CERTS ACE AIE APPLICATIONS
216
NERC Database Server
217
NERC Ethernet (Princeton)
218
NERC Applications And Web Server
214
219
ACE-AIE KEY DATA BROADCAST OVER WEB TO RELIABILITY AUTHORITIES EVERY 60 SECONDS
220
Reliability Authorities (22) Web Browser
222
Early Notification Email Server
(2) ABNORMAL EVENT NOTIFICATION VIA EMAIL
212
(3) MONITORING AND TRACKING BY 22 RELIABILITY AUTHORITIES – GRAPHIC AND GEOGRAPHIC – USING CERTS PERFORMANCE MONITORING TECHNOLOGY PLATFORM

FIG. 15



220
224
226
222
228
VAR
GRID3P
NP 15
SP 15
NORTH
SOUTH
EAST
WEST
DATA COLLECTION
LOGON & PREF.
HELP
GEOGRAPHIC MENU
REAL-TIME MONITORING PANEL
MONITORING
SYSTEM STATUS WINDOW
TEXT WINDOW MENU
ENGINEER'S MODULE MENU
TRACKING
TRACKING PANEL
FORCAST PANEL
PREDICTION
NAVIGATION PAD
DATE/TIME 06/27/2002 14:04:
AUTO REFRESH
CURRENTLY SELECTED:
ALAMIT1
EXP.MW.ACT.MW
ELECTRIC POWER GROUP 11C2003
SCROLL MONITORING
MONITORING DATA
TRACKLING DATA
PRDICTIVE DATA
SCROLLING DATA
TEXT DATA/HORIZONTAL SCROLL
BACK
REPLAY
PANEL
VIEW ANGLE: 90

FIG.16

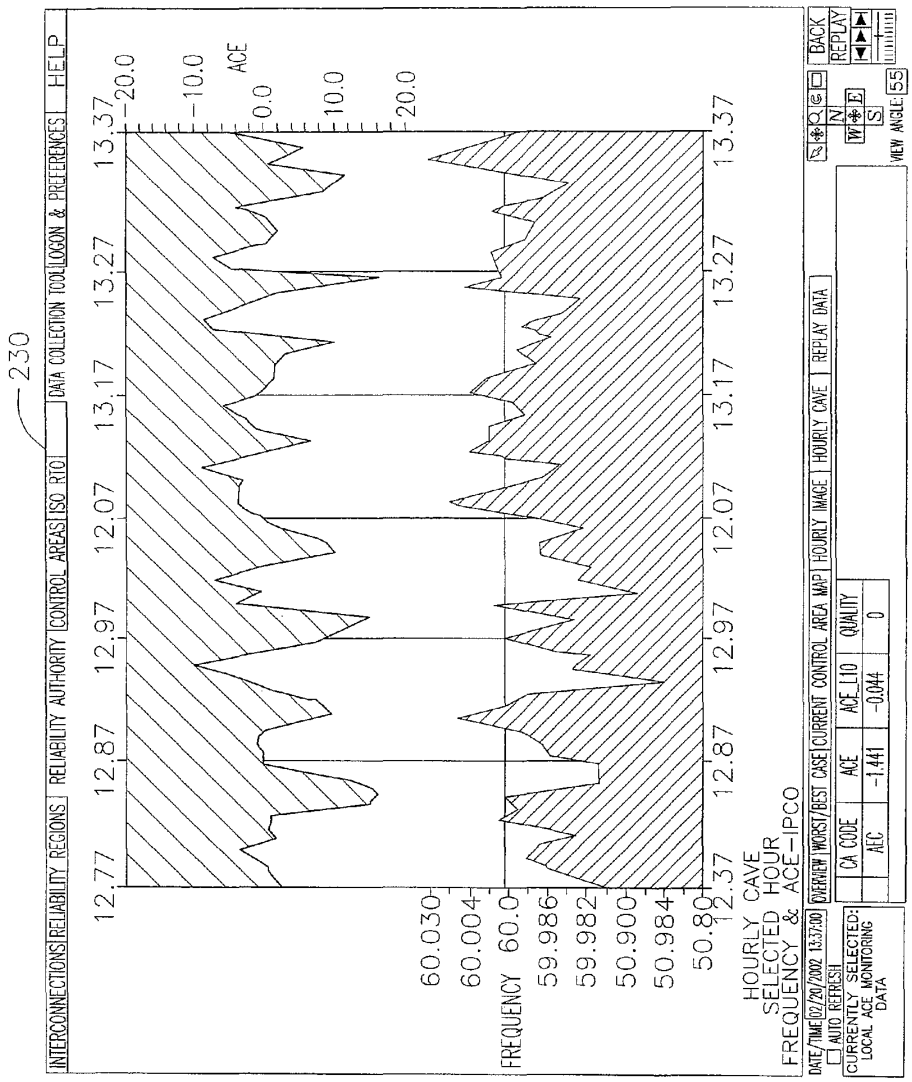
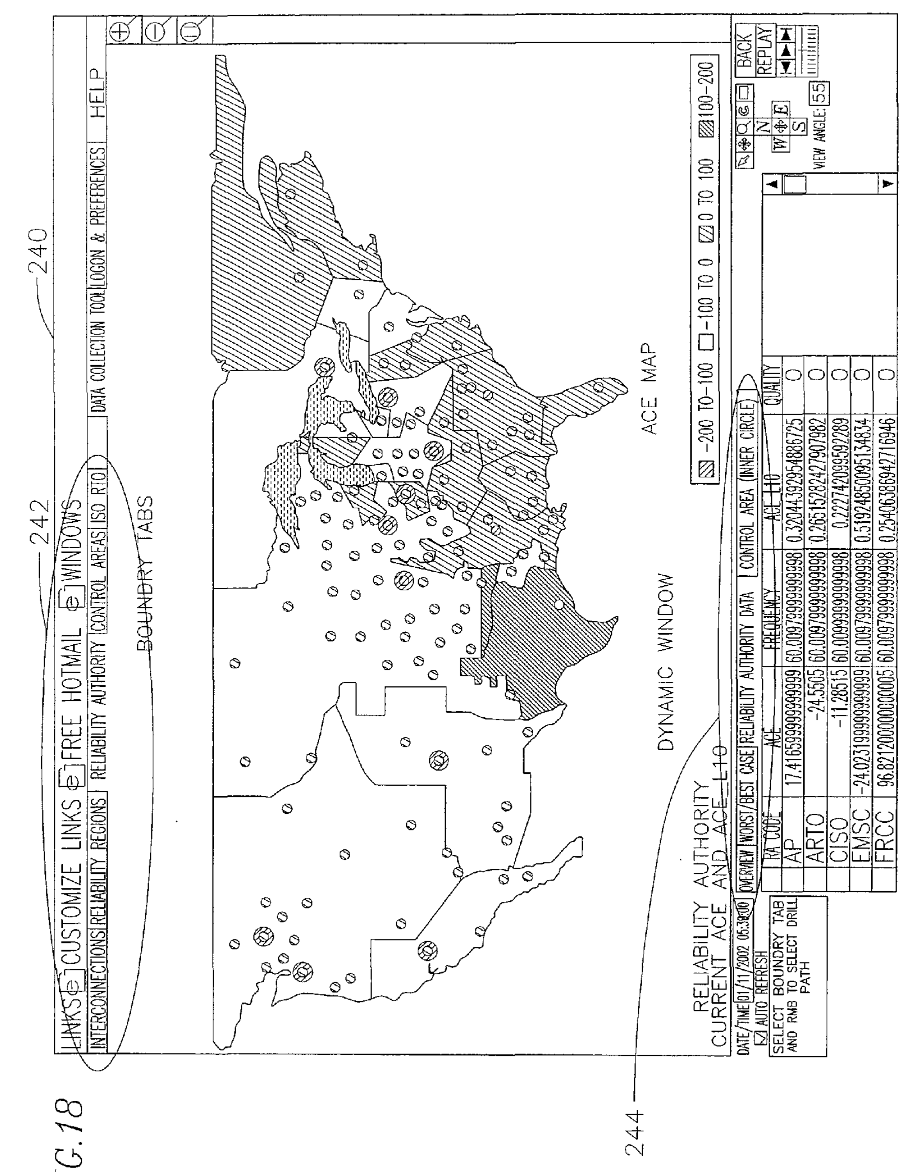

230
INTERCONNECTIONS
RELIABILITY REGIONS
RELIABILITY AUTHORITY
CONTROL AREAS
ISO RTO
DATA COLLECTION TOOL
LOGON & PREFERENCES
HELP
ACE
FREQUENCY
HOURLY CAVE
SELECTED HOUR
FREQUENCY & ACE-IPCO
OVERVIEW
WORST/BEST CASE
CURRENT CONTROL AREA MAP
HOURLY IMAGE
HOURLY CAVE
REPLAY DATA
CA CODE
ACE
ACE_L10
QUALITY
AEC
-1.441
-0.044
0
BACK
REPLAY
VIEW ANGLE 55
AUTO REFRESH
CURRENTLY SELECTED: LOCAL ACE MONITORING DATA

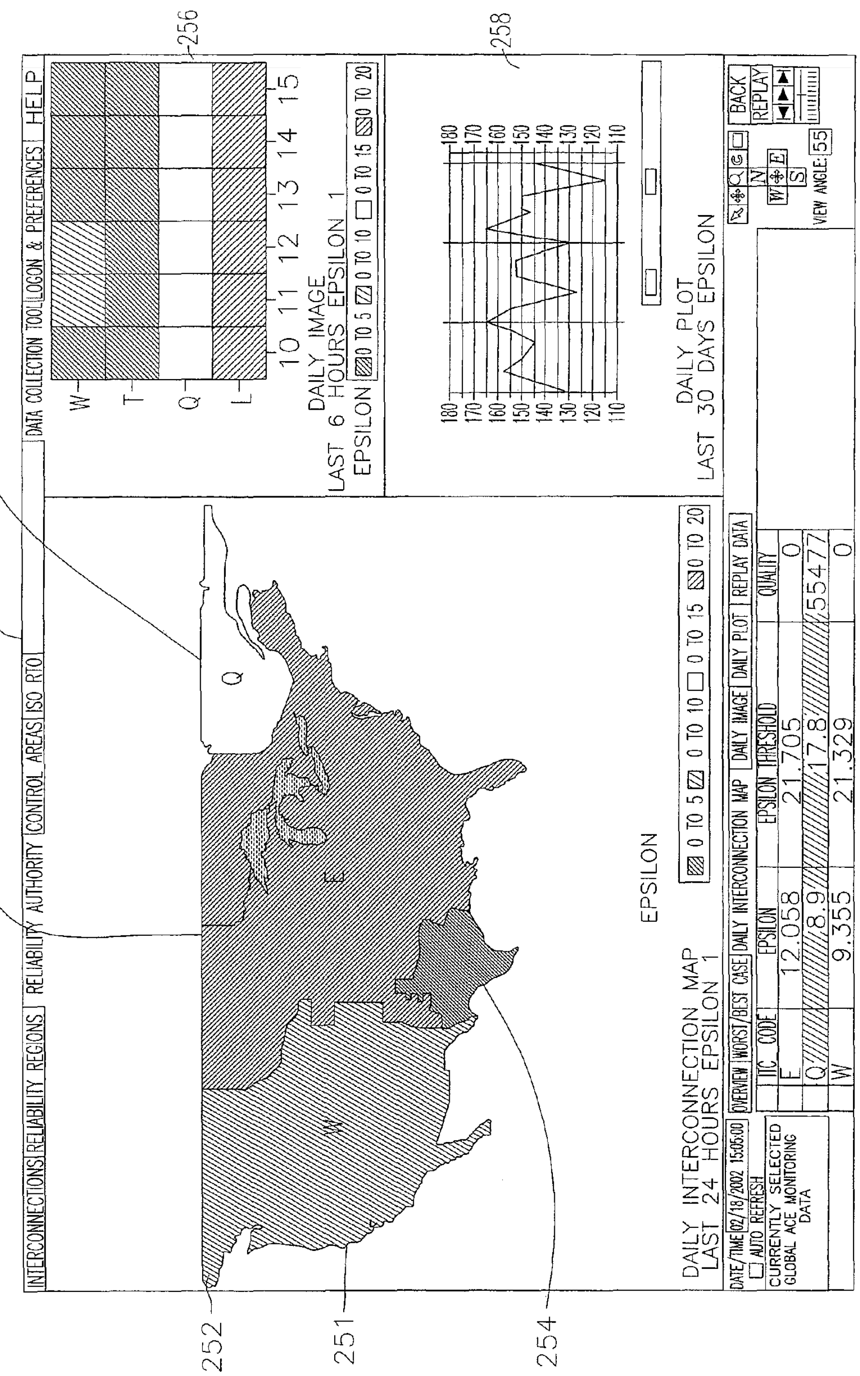
FIG.17



240
242
244
LINKS CUSTOMIZE LINKS FREE HOTMAIL WINDOWS
INTERCONNECTIONS RELIABILITY REGIONS RELIABILITY AUTHORITY CONTROL AREAS ISO RTO DATA COLLECTION TOOL LOGON & PREFERENCES HELP
BOUNDRY TABS
ACE MAP
DYNAMIC WINDOW
RELIABILITY AUTHORITY CURRENT ACE AND ACE_L10
-200 TO-100 -100 TO 0 0 TO 100 100-200
DATE/TIME 01/11/2002 05:38:00
AUTO REFRESH
SELECT BOUNDRY TAB AND RMB TO SELECT DRILL PATH
OVERVIEW WORST/BEST CASE RELIABILITY AUTHORITY DATA CONTROL AREA (INNER CIRCLE)
RA CODE ACE FREQUENCY ACE_L10 QUALITY
AP 17.4165999999999 60.0097999999998 0.32044392954886725 0
ARTO -24.5505 60.0097999999998 0.2651528242790798 0
CISO -11.28515 60.00999999999998 0.2227420958289 0
EMSC -24.02319999999999 60.0097999999998 0.5192485009513464 0
FRCC 96.82120000000005 60.0097999999998 0.2540638694716946 0
BACK REPLAY
N W E S
VIEW ANGLE: 55

FIG. 18

FIG.19



INTERCONNECTIONS
RELIABILITY REGIONS
RELIABILITY AUTHORITY
CONTROL_AREAS
ISO RTO
DATA COLLECTION TOOL
LOGON & PREFERENCES
HELP
DAILY INTERCONNECTION MAP
LAST 24 HOURS EPSILON 1
EPSILON
0 TO 5
0 TO 10
0 TO 15
0 TO 20
DAILY IMAGE
LAST 6 HOURS EPSILON 1
DAILY PLOT
LAST 30 DAYS EPSILON
DATE/TIME 02/18/2002 15:05:00
AUTO REFRESH
CURRENTLY SELECTED GLOBAL ACE MONITORING DATA
OVERVIEW
WORST/BEST CASE
DAILY INTERCONNECTION MAP
DAILY IMAGE
DAILY PLOT
REPLAY DATA
IIC_CODE
EPSILON
EPSILON THRESHOLD
QUALITY
E 12.058 21.705 0
Q 8.9 17.8 .55477
W 9.355 21.329 0
BACK
REPLAY
VIEW ANGLE: 55
250
251
252
253
254
255
256
258

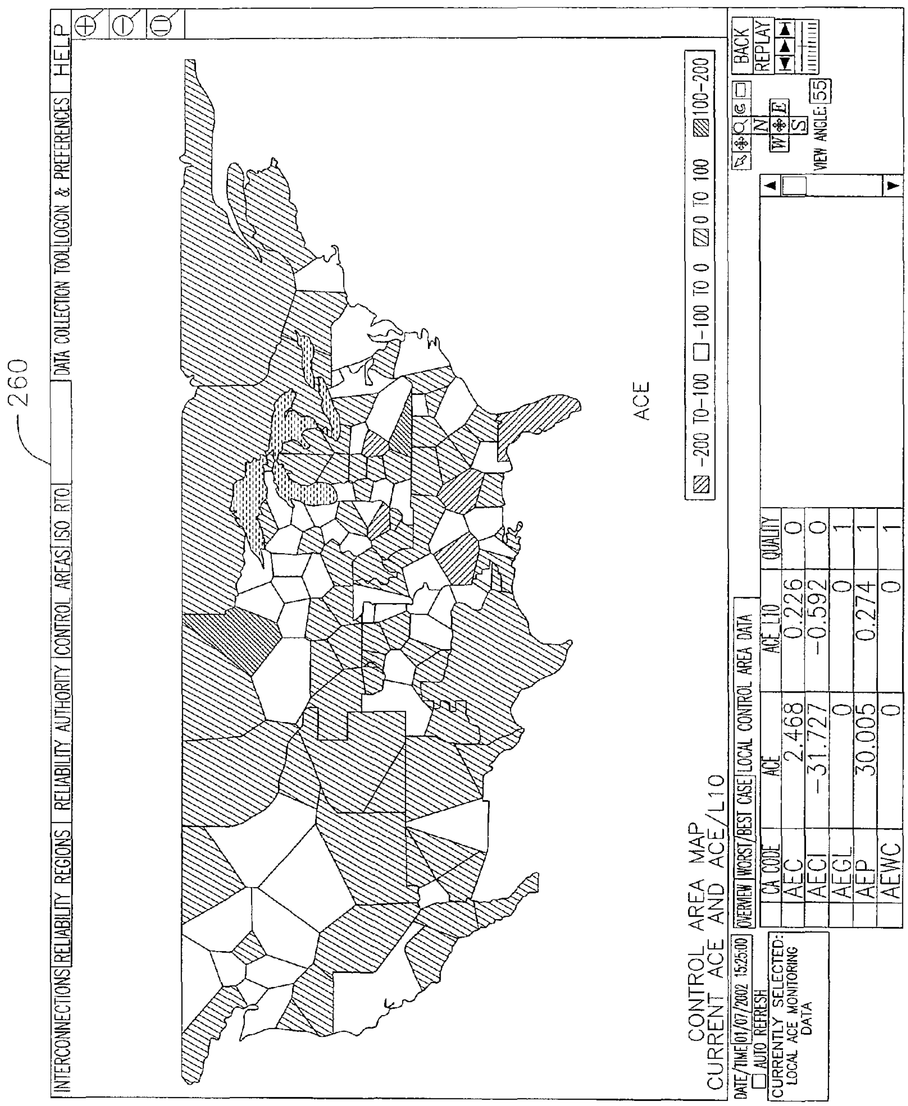
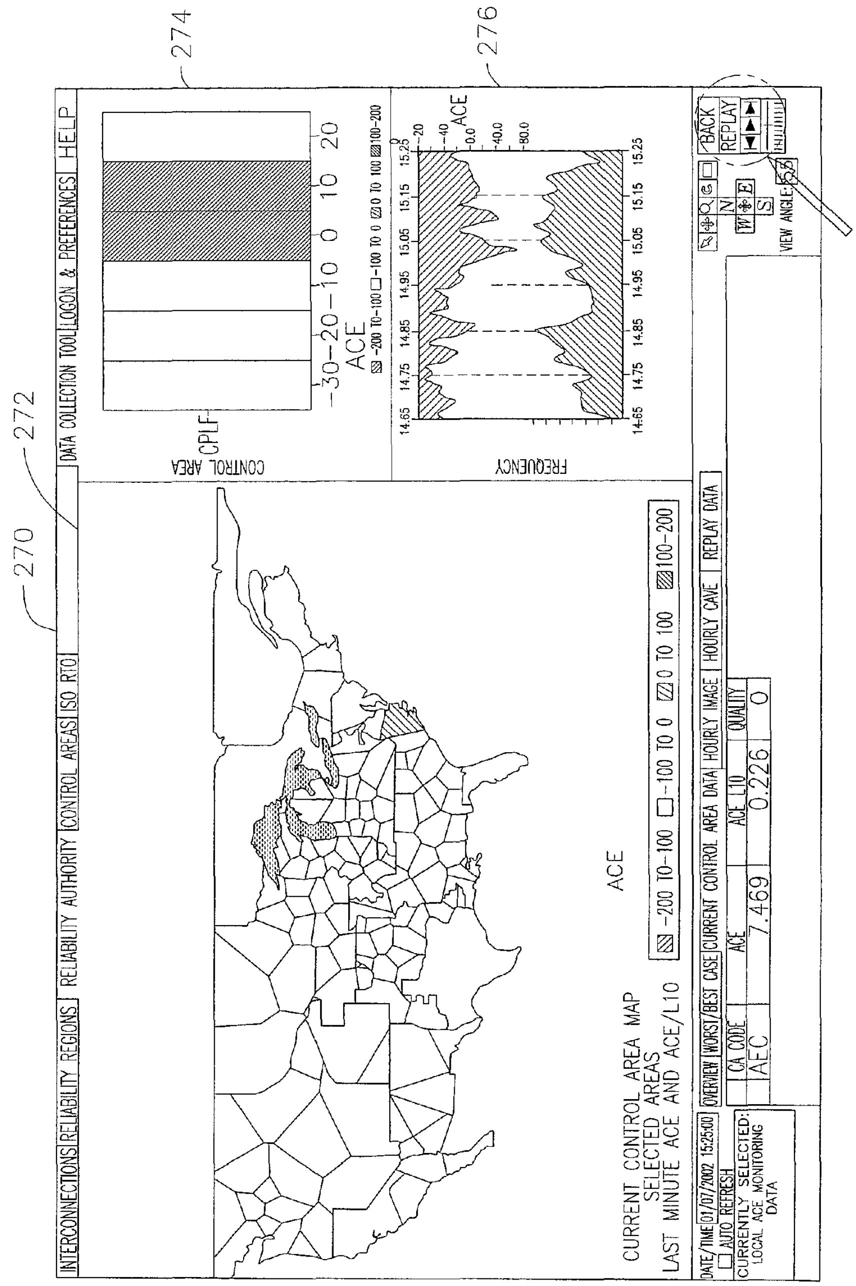

260
INTERCONNECTIONS
RELIABILITY REGIONS
RELIABILITY AUTHORITY
CONTROL AREAS
ISO RTO
DATA COLLECTION TOOL
LOGON & PREFERENCES
HELP
ACE
-200 TO-100
-100 TO 0
0 TO 100
100-200
CONTROL AREA MAP
CURRENT ACE AND ACE/L10
DATE/TIME 01/07/2002 15:25:00
AUTO REFRESH
CURRENTLY SELECTED:
LOCAL ACE MONITORING DATA
OVERVIEW
WORST/BEST CASE
LOCAL CONTROL AREA DATA
CA CODE | ACE | ACE L10 | QUALITY
AEC | 2.468 | 0.226 | 0
AECI | -31.727 | -0.592 | 0
AEGL | 0 | 0 | 1
AEP | 30.005 | 0.274 | 1
AEWC | 0 | 0 | 1
N
W
E
S
VIEW ANGLE: 55
BACK
REPLAY

FIG. 20

FIG. 21


274
276
272
270
INTERCONNECTIONS
RELIABILITY REGIONS
RELIABILITY AUTHORITY
CONTROL AREAS
ISO RTO
DATA COLLECTION TOOL
LOGON & PREFERENCES
HELP
CONTROL AREA
CPLF
ACE
FREQUENCY
CURRENT CONTROL AREA MAP
SELECTED AREAS
LAST MINUTE ACE AND ACE/L10
-200 TO -100
-100 TO 0
0 TO 100
100-200
DATE/TIME 01/07/2002 15:25:00
AUTO REFRESH
CURRENTLY SELECTED:
LOCAL ACE MONITORING DATA
OVERVIEW
WORST/BEST CASE
CURRENT CONTROL AREA DATA
HOURLY IMAGE
HOURLY CAVE
REPLAY DATA
CA CODE
AEC
7.469
ACE L10
0.226
QUALITY
0
BACK
REPLAY
VIEW ANGLE:

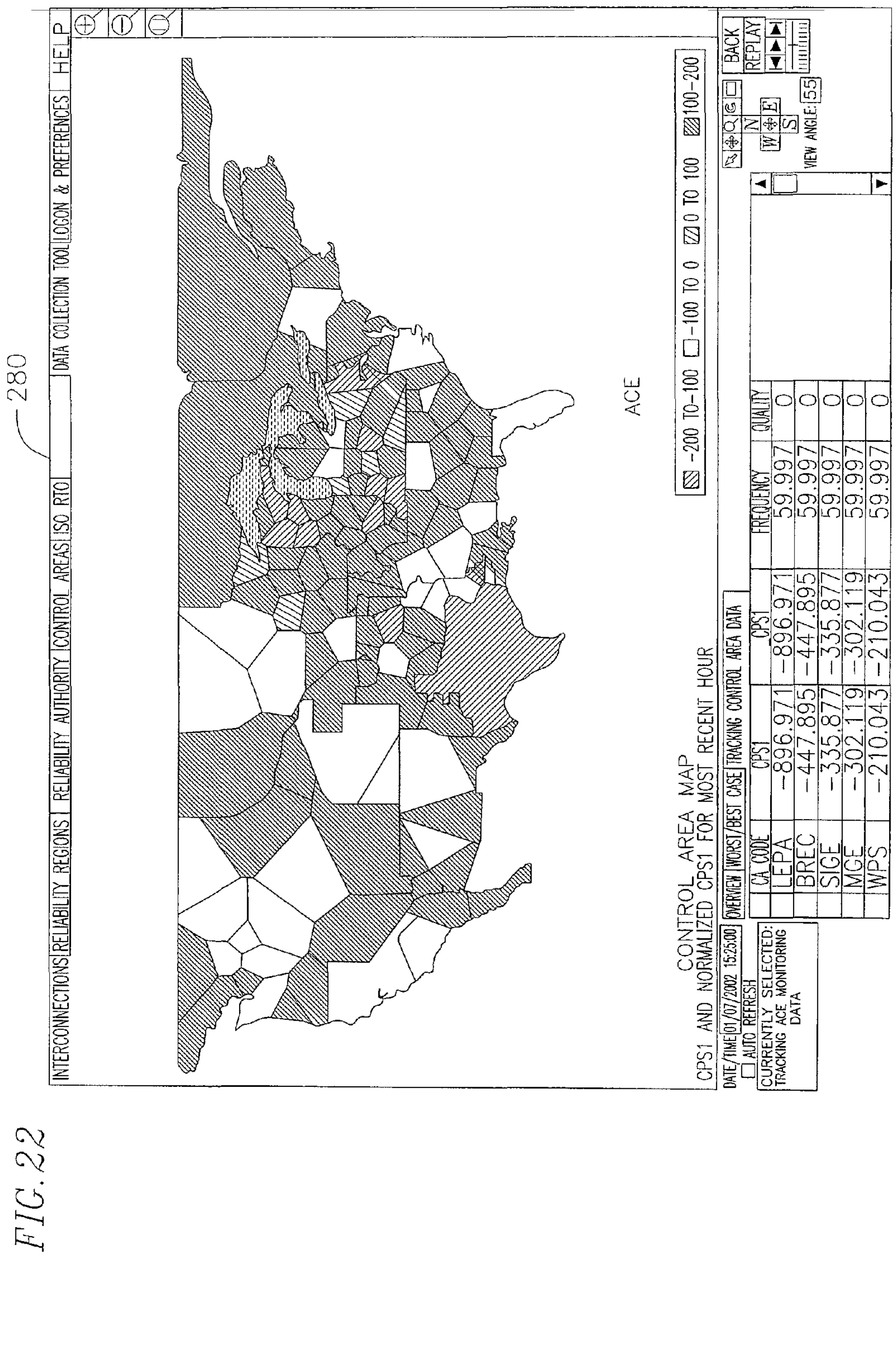
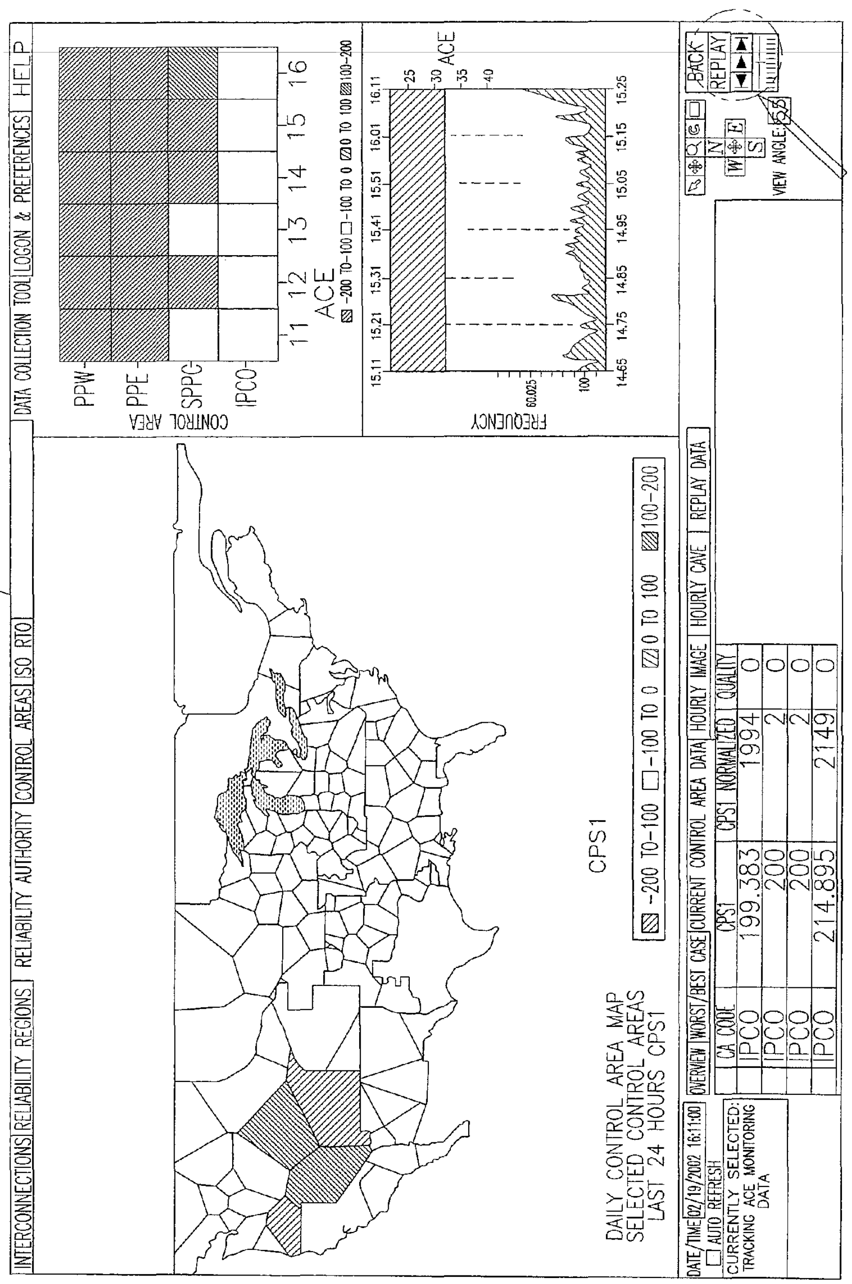
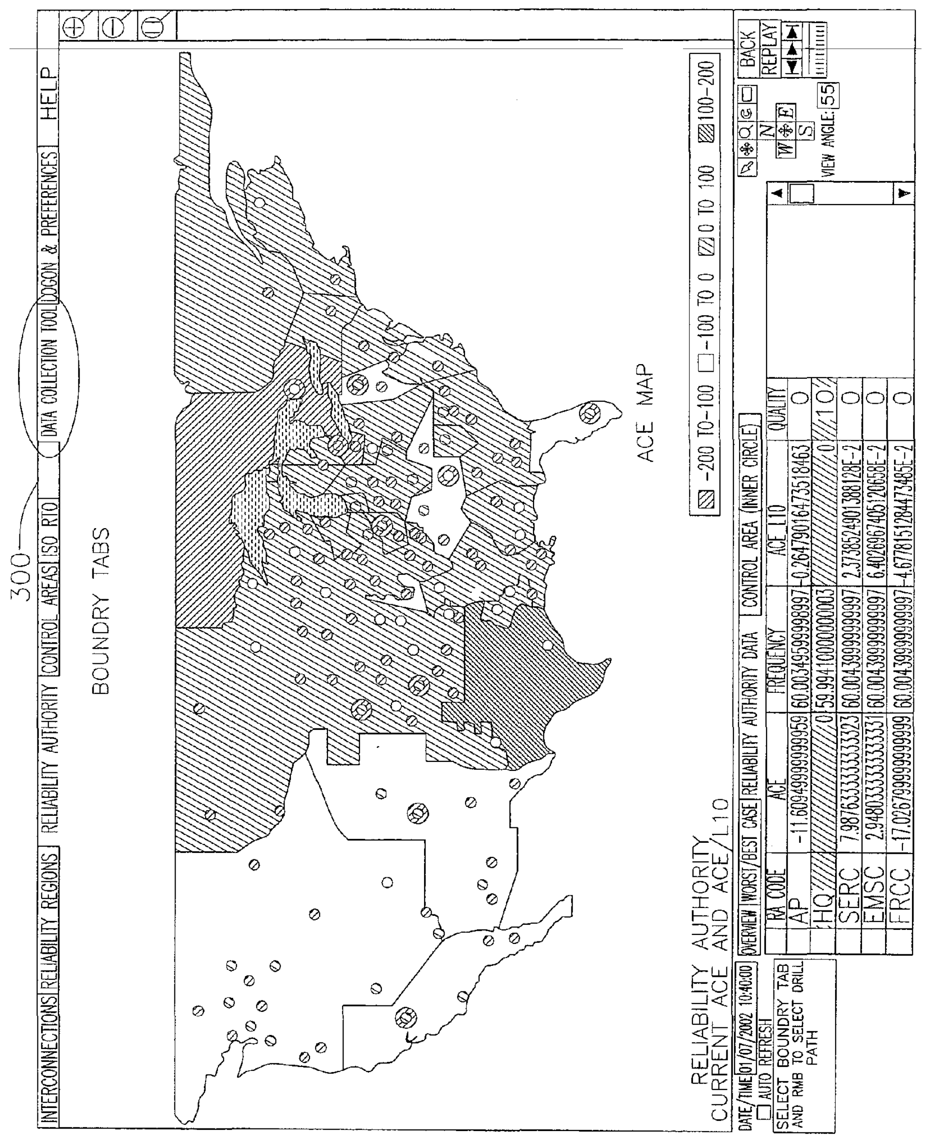

280
INTERCONNECTIONS
RELIABILITY REGIONS
RELIABILITY AUTHORITY
CONTROL AREAS
ISO RTO
DATA COLLECTION TOOL
LOGON & PREFERENCES
HELP
-200 TO -100
-100 TO 0
0 TO 100
100-200
ACE
CONTROL AREA MAP
CPS1 AND NORMALIZED CPS1 FOR MOST RECENT HOUR
DATE/TIME 01/07/2002 15:26:00
AUTO REFRESH
CURRENTLY SELECTED: TRACKING ACE MONITORING DATA
OVERVIEW
WORST/BEST CASE
TRACKING CONTROL AREA DATA
CA CODE CPS1 CPS1 FREQUENCY QUALITY
LEPA -896.971 -896.971 59.997 0
BREC -447.895 -447.895 59.997 0
SIGE -335.877 -335.877 59.997 0
MGE -302.119 -302.119 59.997 0
WPS -210.043 -210.043 59.997 0
N
W E
S
VIEW ANGLE: 55
BACK
REPLAY

FIG. 22

FIG. 23

290


INTERCONNECTIONS
RELIABILITY REGIONS
RELIABILITY AUTHORITY
CONTROL AREAS
ISO RTO
DATA COLLECTION TOOL
LOGON & PREFERENCES
HELP
DAILY CONTROL AREA MAP
SELECTED CONTROL AREAS
LAST 24 HOURS CPS1
CPS1
-200 TO-100
-100 TO 0
0 TO 100
100-200
CONTROL AREA
PPW
PPE
SPPG
IPCO
ACE
FREQUENCY
BACK
REPLAY
VIEW ANGLE
OVERVIEW
WORST/BEST CASE
CURRENT CONTROL AREA DATA
HOURLY IMAGE
HOURLY CAVE
REPLAY DATA
DATE/TIME 02/19/2002 16:11:00
AUTO REFRESH
CURRENTLY SELECTED:
TRACKING ACE MONITORING DATA
CA CODE
CPS1
CPS1 NORMALIZED
QUALITY
IPCO
199.383
1994
0
IPCO
200
2
0
IPCO
200
2
0
IPCO
214.895
2149
0



300
INTERCONNECTIONS
RELIABILITY REGIONS
RELIABILITY AUTHORITY
CONTROL AREAS
ISO RTO
DATA COLLECTION TOOL
LOGON & PREFERENCES
HELP
BOUNDRY TABS
ACE MAP
-200 TO-100
-100 TO 0
0 TO 100
100-200
RELIABILITY AUTHORITY
CURRENT ACE AND ACE/L10
DATE/TIME 01/07/2002 10:40:00
AUTO REFRESH
SELECT BOUNDRY TAB AND RMB TO SELECT DRILL PATH
OVERVIEW
WORST/BEST CASE
RELIABILITY AUTHORITY DATA
CONTROL AREA (INNER CIRCLE)
RA CODE | ACE | FREQUENCY | ACE_L10 | QUALITY
AP | -11.60949999999959 | 60.00349599998997 | -0.26479016473518463 | 0
HQ | 0 | 59.99410000000003 | 0 | 10
SERC | 7.98763333333333323 | 60.00439999999997 | 2.3738524901388128E-2 | 0
EMSC | 2.948033333333331 | 60.00439999999997 | 6.4026967405120658E-2 | 0
FRCC | -17.02679999999999 | 60.00439999999997 | -4.6778151284473485E-2 | 0
N
W
E
S
VIEW ANGLE: 55
BACK
REPLAY

FIG. 24

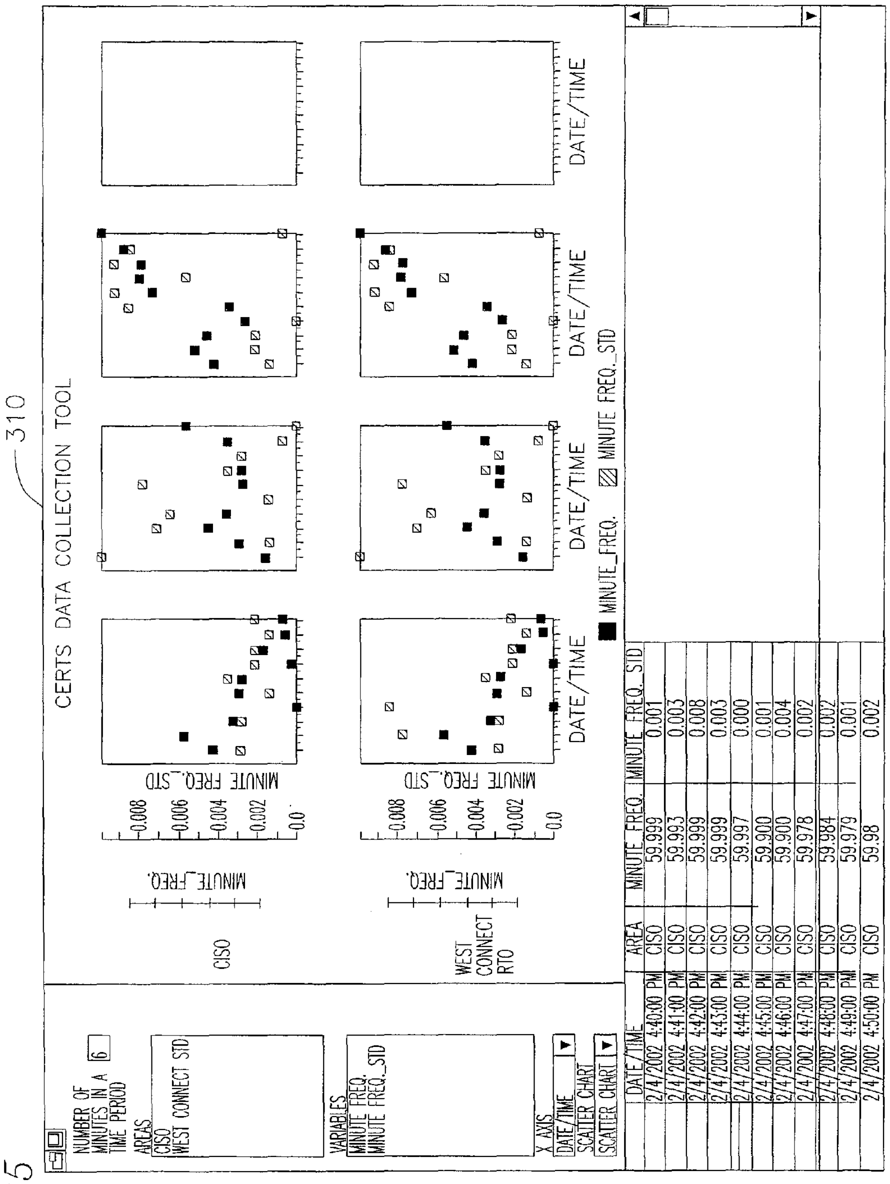

310
CERTS DATA COLLECTION TOOL
NUMBER OF MINUTES IN A TIME PERIOD
6
AREAS
CISO
WEST CONNECT STD
VARIABLES
MINUTE FREQ.
MINUTE FREQ._STD
X AXIS
DATE/TIME
SCATTER CHART
SCATTER CHART
CISO
WEST CONNECT RTO
MINUTE_FREQ.
MINUTE FREQ._STD
0.008
0.006
0.004
0.002
0.0
DATE/TIME
MINUTE_FREQ.
MINUTE FREQ._STD
DATE/TIME
AREA
MINUTE_FREQ.
MINUTE_FREQ._STD
2/4/2002 4:40:00 PM CISO 59.999 0.001
2/4/2002 4:41:00 PM CISO 59.993 0.003
2/4/2002 4:42:00 PM CISO 59.999 0.008
2/4/2002 4:43:00 PM CISO 59.999 0.003
2/4/2002 4:44:00 PM CISO 59.997 0.000
2/4/2002 4:45:00 PM CISO 59.900 0.001
2/4/2002 4:46:00 PM CISO 59.900 0.004
2/4/2002 4:47:00 PM CISO 59.978 0.002
2/4/2002 4:48:00 PM CISO 59.984 0.002
2/4/2002 4:49:00 PM CISO 59.979 0.001
2/4/2002 4:50:00 PM CISO 59.98 0.002

FIG. 25

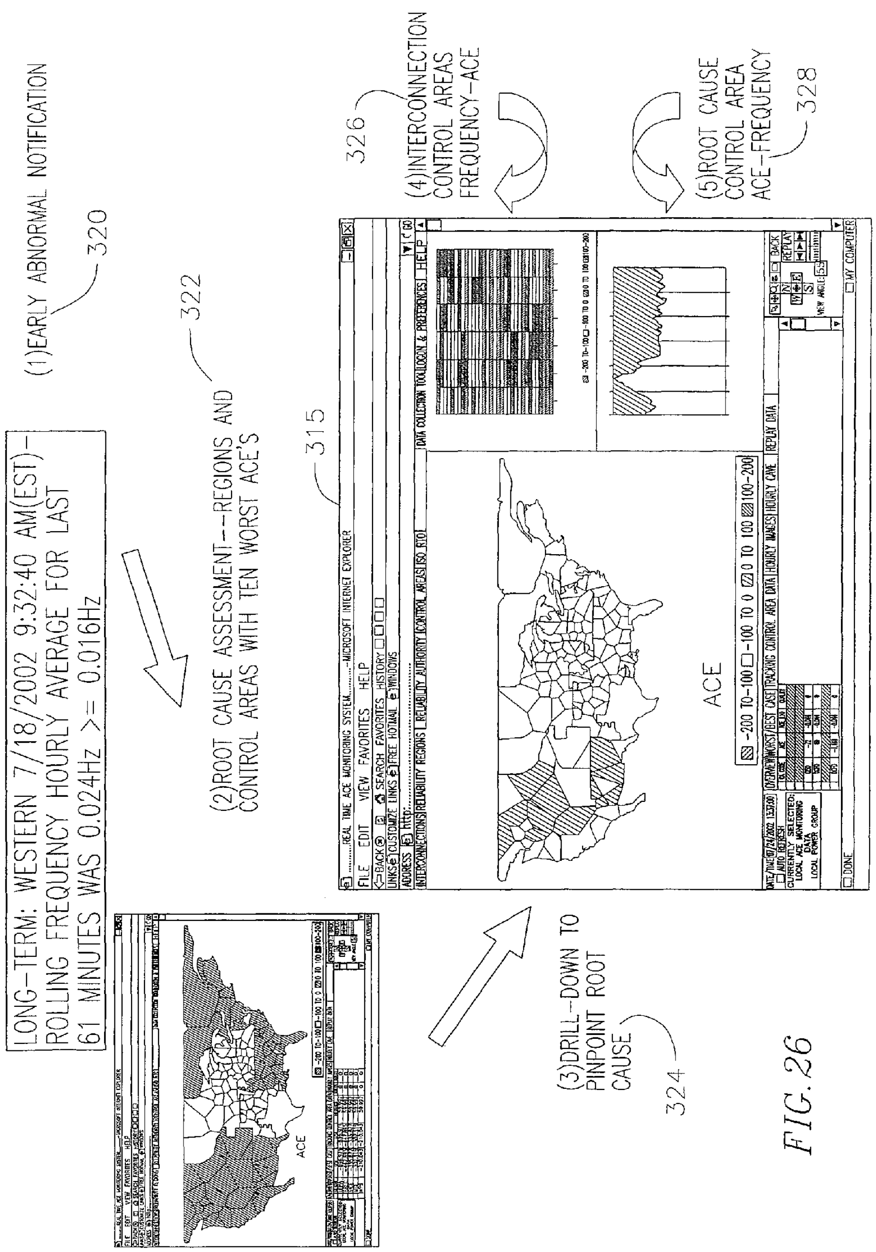
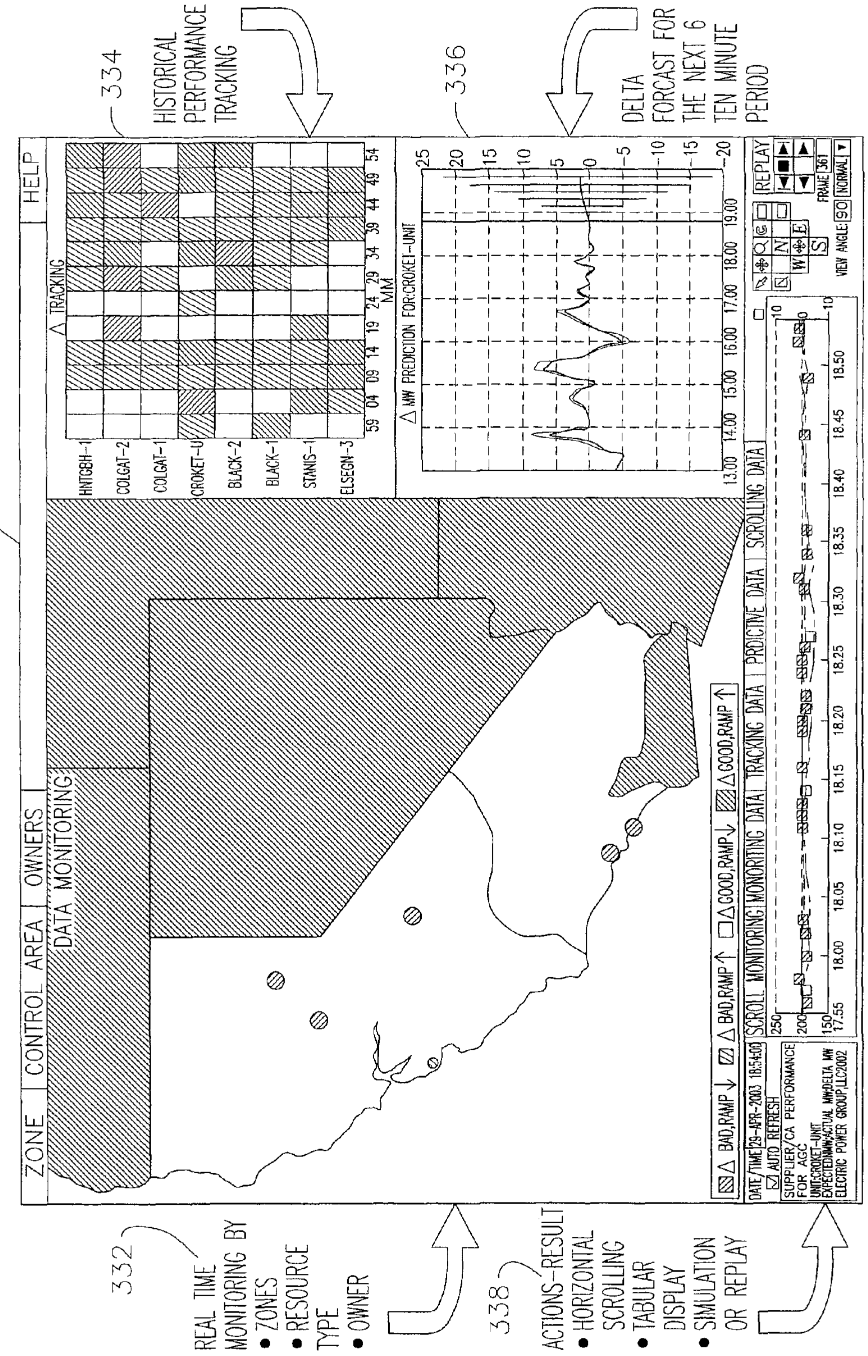
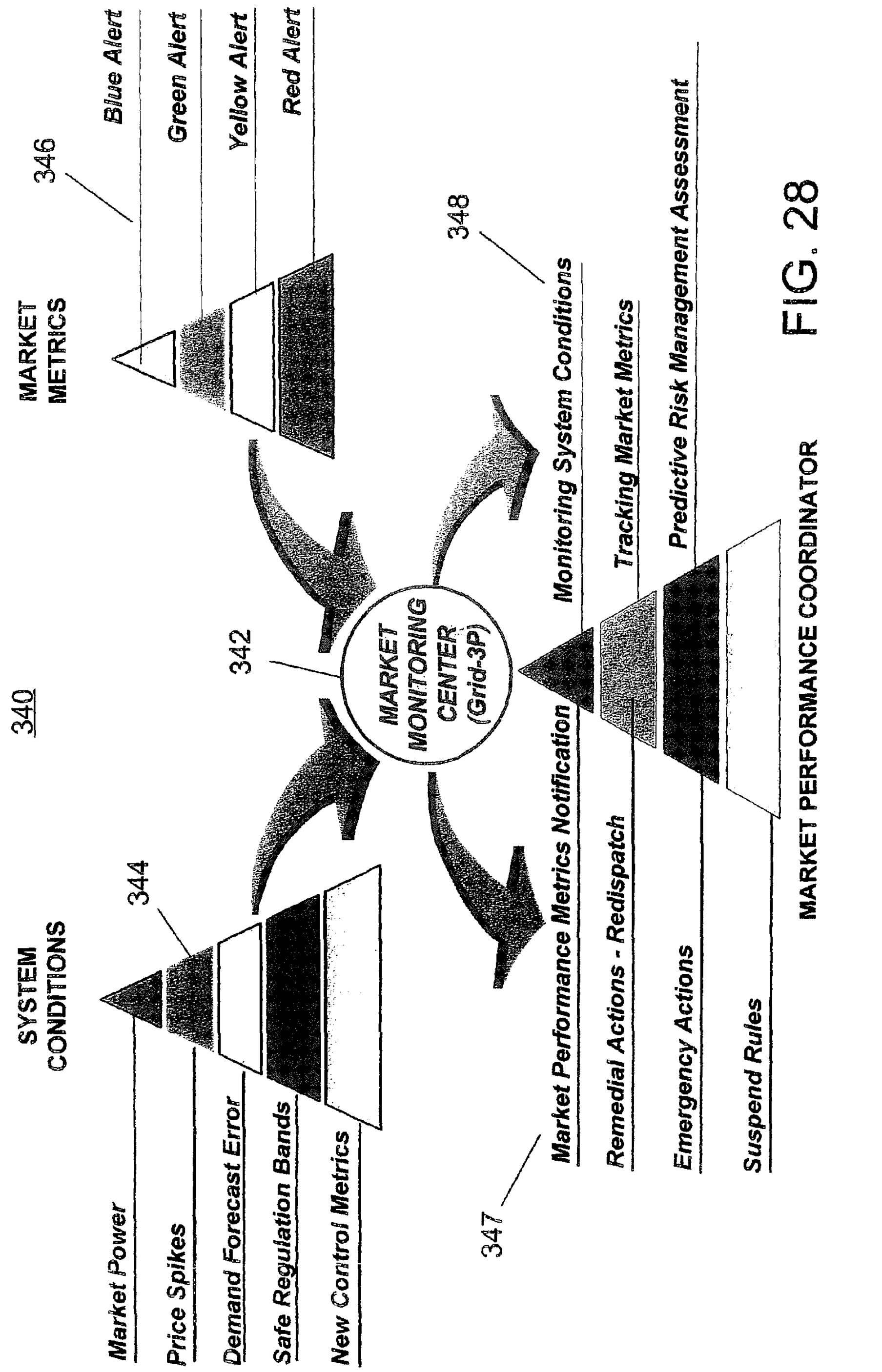

LONG-TERM: WESTERN 7/18/2002 9:32:40 AM(EST)-ROLLING FREQUENCY HOURLY AVERAGE FOR LAST 61 MINUTES WAS 0.024Hz >= 0.016Hz
(1)EARLY ABNORMAL NOTIFICATION
320
(2)ROOT CAUSE ASSESSMENT--REGIONS AND CONTROL AREAS WITH TEN WORST ACE'S
322
315
(3)DRILL-DOWN TO PINPOINT ROOT CAUSE
324
(4)INTERCONNECTION CONTROL AREAS FREQUENCY-ACE
326
(5)ROOT CAUSE CONTROL AREA ACE-FREQUENCY
328
ACE

FIG. 26

FIG. 27

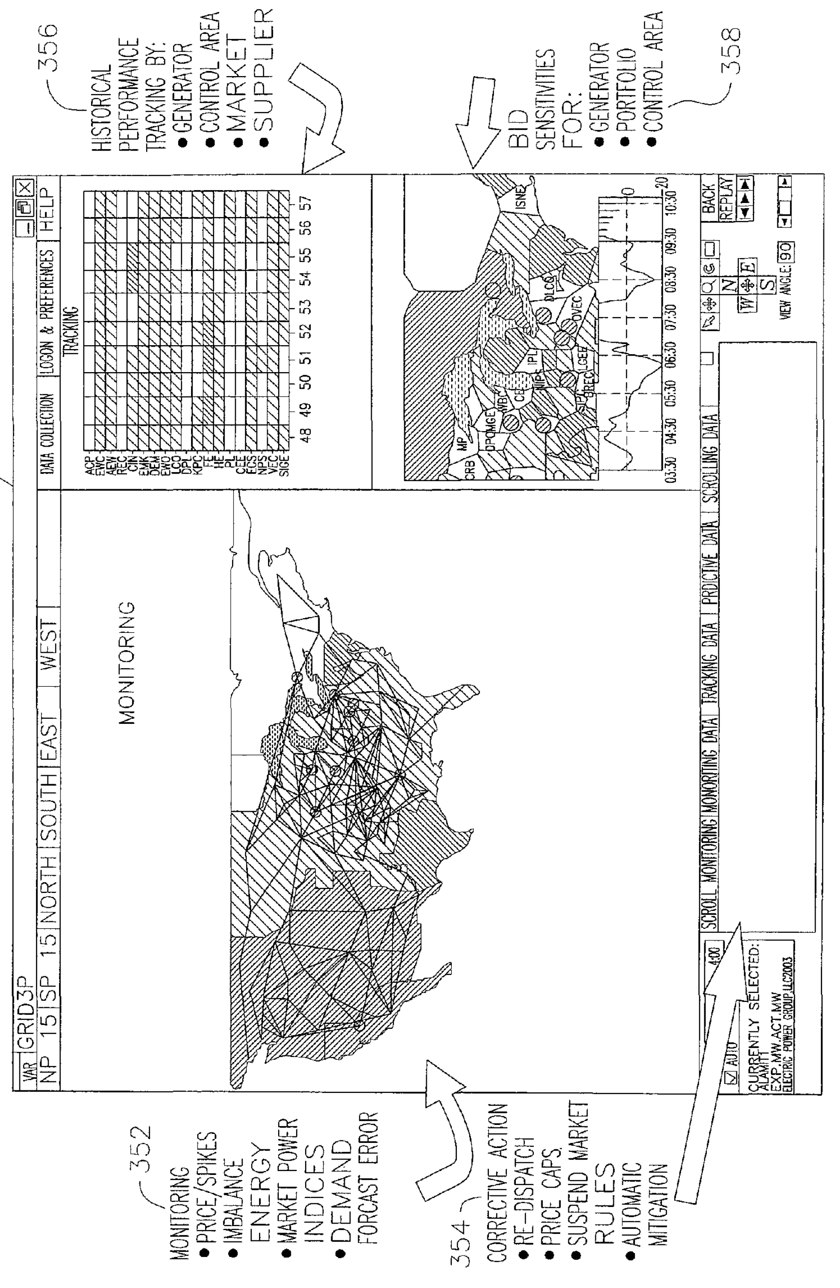

330
334
HISTORICAL PERFORMANCE TRACKING
336
DELTA FORCAST FOR THE NEXT 6 TEN MINUTE PERIOD
332
REAL TIME MONITORING BY
• ZONES
• RESOURCE TYPE
• OWNER
338
ACTIONS–RESULT
• HORIZONTAL SCROLLING TABULAR DISPLAY
• SIMULATION OR REPLAY
ZONE
CONTROL AREA
OWNERS
HELP
DATA MONITORING
TRACKING
HNTGBH–1
COLGAT–2
COLGAT–1
CROKET–U
BLACK–2
BLACK–1
STANIS–1
ELSEGN–3
MM
MW PREDICTION FOR:CROKET–UNIT
BAD,RAMP
GOOD,RAMP
SCROLL MONITORING
MONORITING DATA
TRACKING DATA
PRDICTIVE DATA
SCROLLING DATA
REPLAY
AUTO REFRESH
SUPPLIER/CA PERFORMANCE FOR AGC
VIEW ANGLE
FRAME
NORMAL



340
SYSTEM CONDITIONS
344
Market Power
Price Spikes
Demand Forecast Error
Safe Regulation Bands
New Control Metrics
MARKET METRICS
346
Blue Alert
Green Alert
Yellow Alert
Red Alert
342
MARKET MONITORING CENTER (Grid-3P)
347
Market Performance Metrics Notification
Remedial Actions - Redispatch
Emergency Actions
Suspend Rules
348
Monitoring System Conditions
Tracking Market Metrics
Predictive Risk Management Assessment
MARKET PERFORMANCE COORDINATOR

FIG. 28

FIG. 29


350
356
HISTORICAL PERFORMANCE TRACKING BY:
• GENERATOR
• CONTROL AREA
• MARKET
• SUPPLIER
358
BID SENSITIVITIES FOR:
• GENERATOR
• PORTFOLIO
• CONTROL AREA
352
MONITORING
• PRICE/SPIKES
• IMBALANCE ENERGY
• MARKET POWER INDICES
• DEMAND FORCAST ERROR
354
CORRECTIVE ACTION
• RE-DISPATCH
• PRICE CAPS
• SUSPEND MARKET RULES
• AUTOMATIC MITIGATION
VAR GRID3P
NP 15 SP 15 NORTH SOUTH EAST WEST
MONITORING
DATA COLLECTION
LOGON & PREFERENCES
HELP
TRACKING
SCROLL MONITORING
MONIORTING DATA
TRACKING DATA
PRDICTIVE DATA
SCROLLING DATA
BACK
REPLAY
CURRENTLY SELECTED:
VIEW ANGLE 90

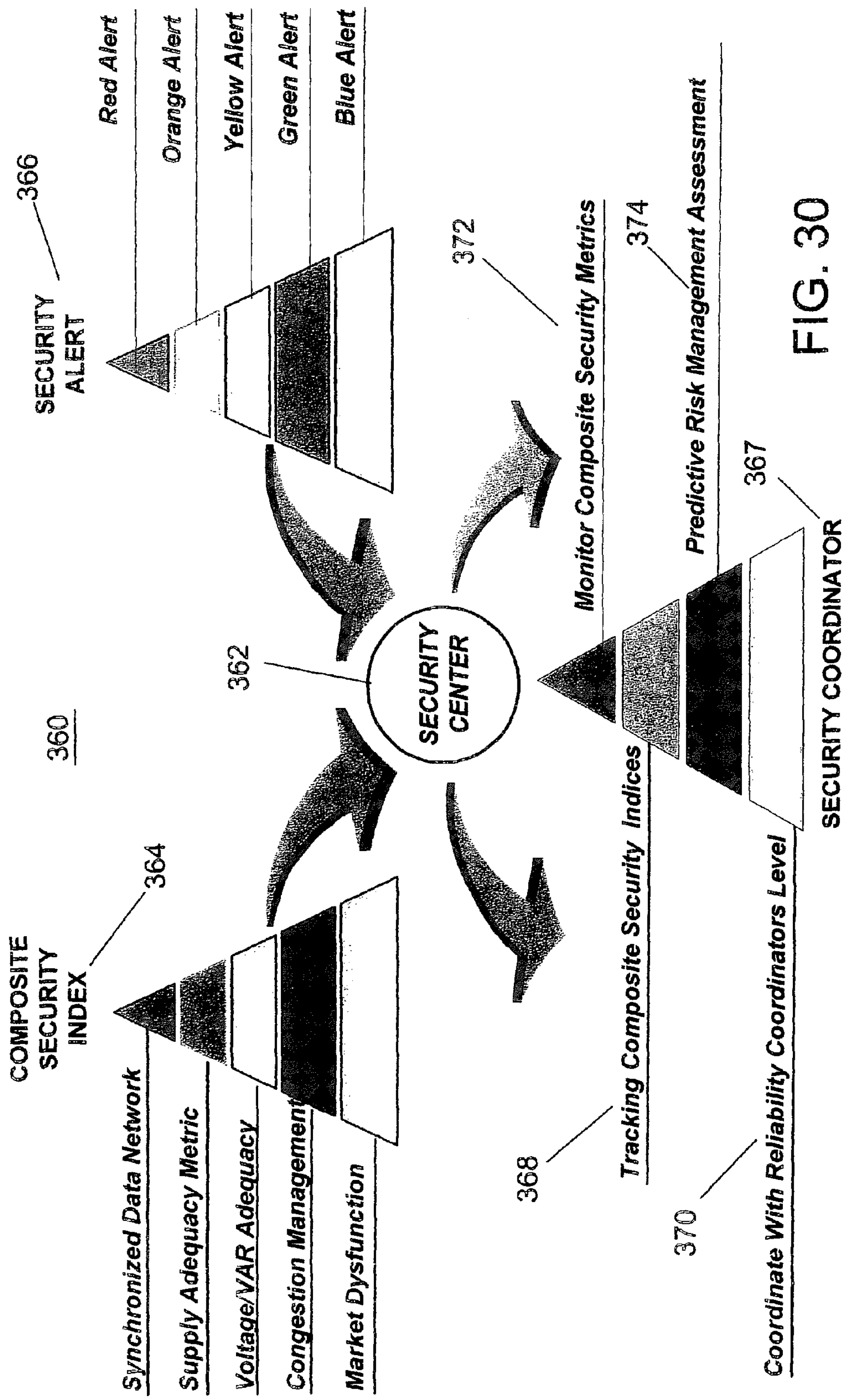
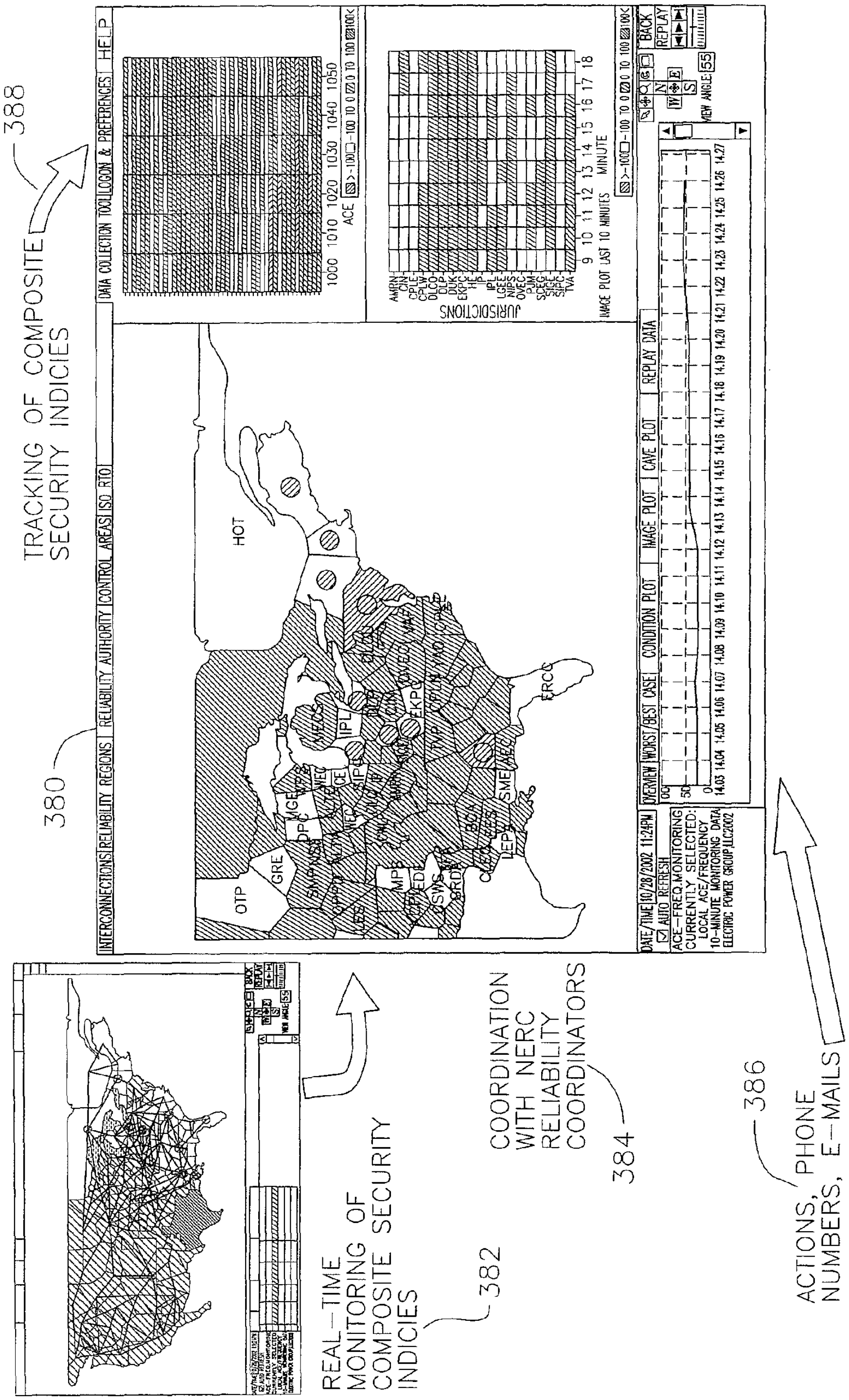
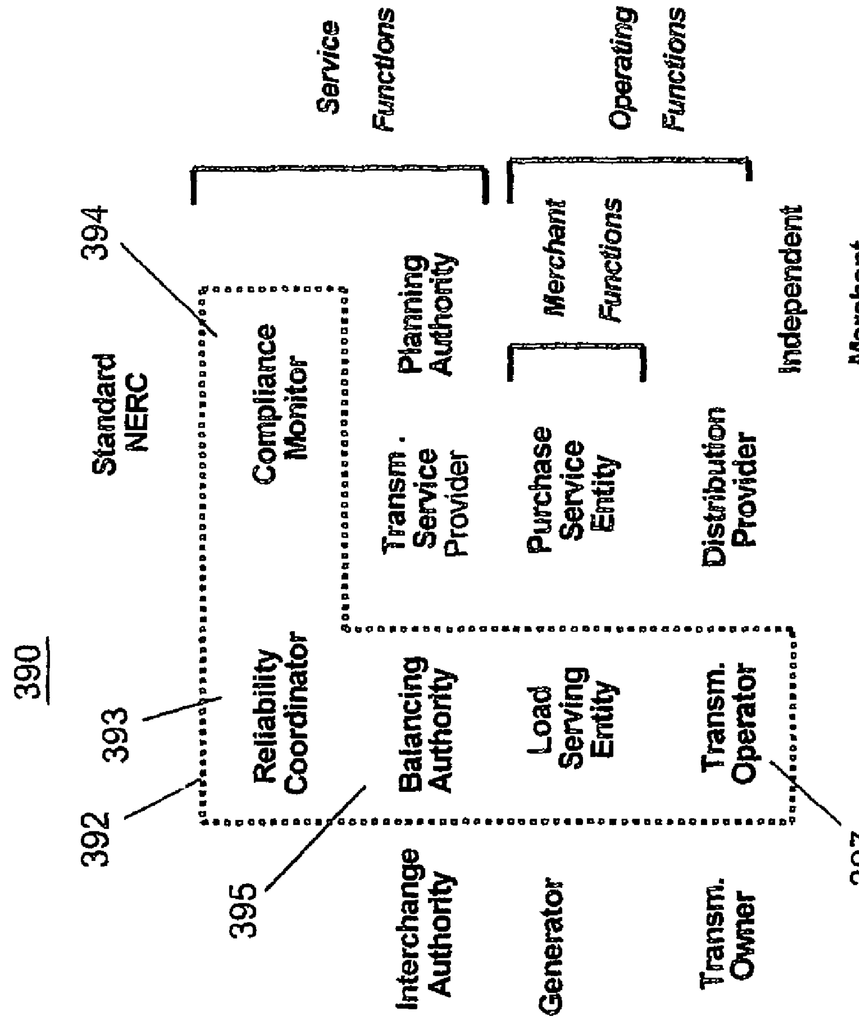

360
COMPOSITE SECURITY INDEX
364
Synchronized Data Network
Supply Adequacy Metric
Voltage/VAR Adequacy
Congestion Management
Market Dysfunction
SECURITY ALERT
366
Red Alert
Orange Alert
Yellow Alert
Green Alert
Blue Alert
362
SECURITY CENTER
372
Monitor Composite Security Metrics
374
Predictive Risk Management Assessment
367
SECURITY COORDINATOR
368
Tracking Composite Security Indices
370
Coordinate With Reliability Coordinators Level

FIG. 30

FIG. 31


TRACKING OF COMPOSITE SECURITY INDICIES
388
380
REAL-TIME MONITORING OF COMPOSITE SECURITY INDICIES
382
COORDINATION WITH NERC RELIABILITY COORDINATORS
384
ACTIONS, PHONE NUMBERS, E-MAILS
386
INTERCONNECTIONS
RELIABILITY REGIONS
RELIABILITY AUTHORITY
CONTROL AREAS
ISO RTO
DATA COLLECTION TOOL
LOGON & PREFERENCES
HELP
JURISDICTIONS
IMAGE PLOT LAST 10 MINUTES
MINUTE
OVERVIEW
WORST/BEST CASE
CONDITION PLOT
IMAGE PLOT
CAVE PLOT
REPLAY DATA
BACK
REPLAY
VIEW ANGLE
DATE/TIME 10/28/2002 11:24PM
AUTO REFRESH
HOT
OTP
GRE
ERCO



390
Standard NERC
392
393
394
395
397
Reliability Coordinator
Compliance Monitor
Balancing Authority
Transm. Service Provider
Planning Authority
Service Functions
Interchange Authority
Generator
Load Serving Entity
Purchase Service Entity
Merchant Functions
Operating Functions
Transm. Owner
Transm. Operator
Distribution Provider
Independent Merchant

FIG. 32

440

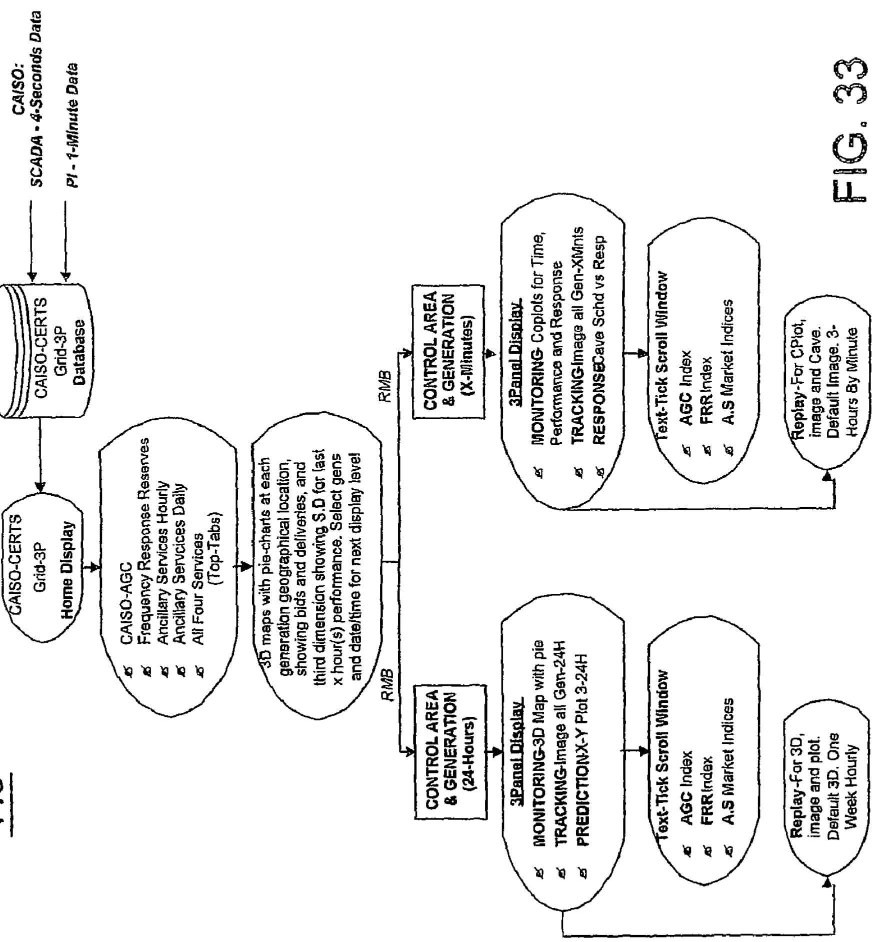
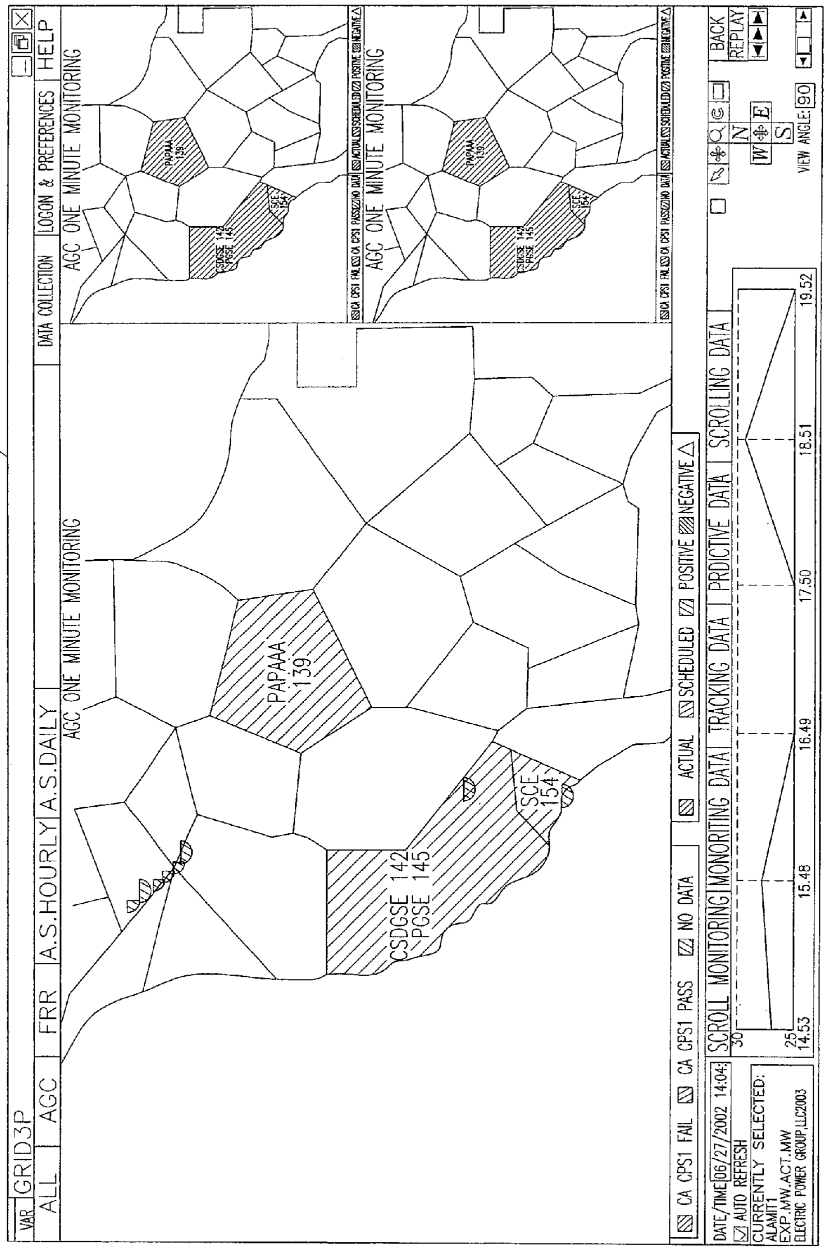

CAISO:
SCADA - 4-Seconds Data
PI - 1-Minute Data
CAISO-CERTS Grid-3P Database
CAISO-CERTS Grid-3P Home Display
CAISO-AGC
Frequency Response Reserves
Ancillary Services Hourly
Ancillary Services Daily
All Four Services (Top-Tabs)
3D maps with pie-charts at each generation geographical location, showing bids and deliveries, and third dimension showing S.D for last x hour(s) performance. Select gens and date/time for next display level
RMB
RMB
CONTROL AREA & GENERATION (24-Hours)
CONTROL AREA & GENERATION (X-Minutes)
3Panel Display
MONITORING-3D Map with pie
TRACKING-Image all Gen-24H
PREDICTION-X-Y Plot 3-24H
3Panel Display
MONITORING-Cplots for Time, Performance and Response
TRACKING-Image all Gen-XMnts
RESPONSE-Cave Schd vs Resp
Text-Tick Scroll Window
AGC Index
FRR Index
A.S Market Indices
Text-Tick Scroll Window
AGC Index
FRR Index
A.S Market Indices
Replay-For 3D, image and plot. Default 3D. One Week Hourly
Replay-For CPlot, image and Cave. Default Image. 3-Hours By Minute

FIG. 33

FIG.34

450



VAR GRID3P
ALL
AGC
FRR
A.S.HOURLY
A.S.DAILY
DATA COLLECTION
LOGON & PREFERENCES
HELP
AGC ONE MINUTE MONITORING
PAPAAA 139
CSDGSE 142
PGSE 145
SCE 154
CA CPS1 FAIL
CA CPS1 PASS
NO DATA
ACTUAL
SCHEDULED
POSITIVE
NEGATIVE
DATE/TIME 06/27/2002 14:04:
AUTO REFRESH
CURRENTLY SELECTED:
ALAMIT1
EXP:MW.ACT.MW
ELECTRIC POWER GROUP,LLC2003
SCROLL MONITORING
MONORITING DATA
TRACKING DATA
PRDICTIVE DATA
SCROLLING DATA
30
25
14.53
15.48
16.49
17.50
18.51
19.52
N
W
E
S
VIEW ANGLE: 90
BACK
REPLAY

FIG. 35

460

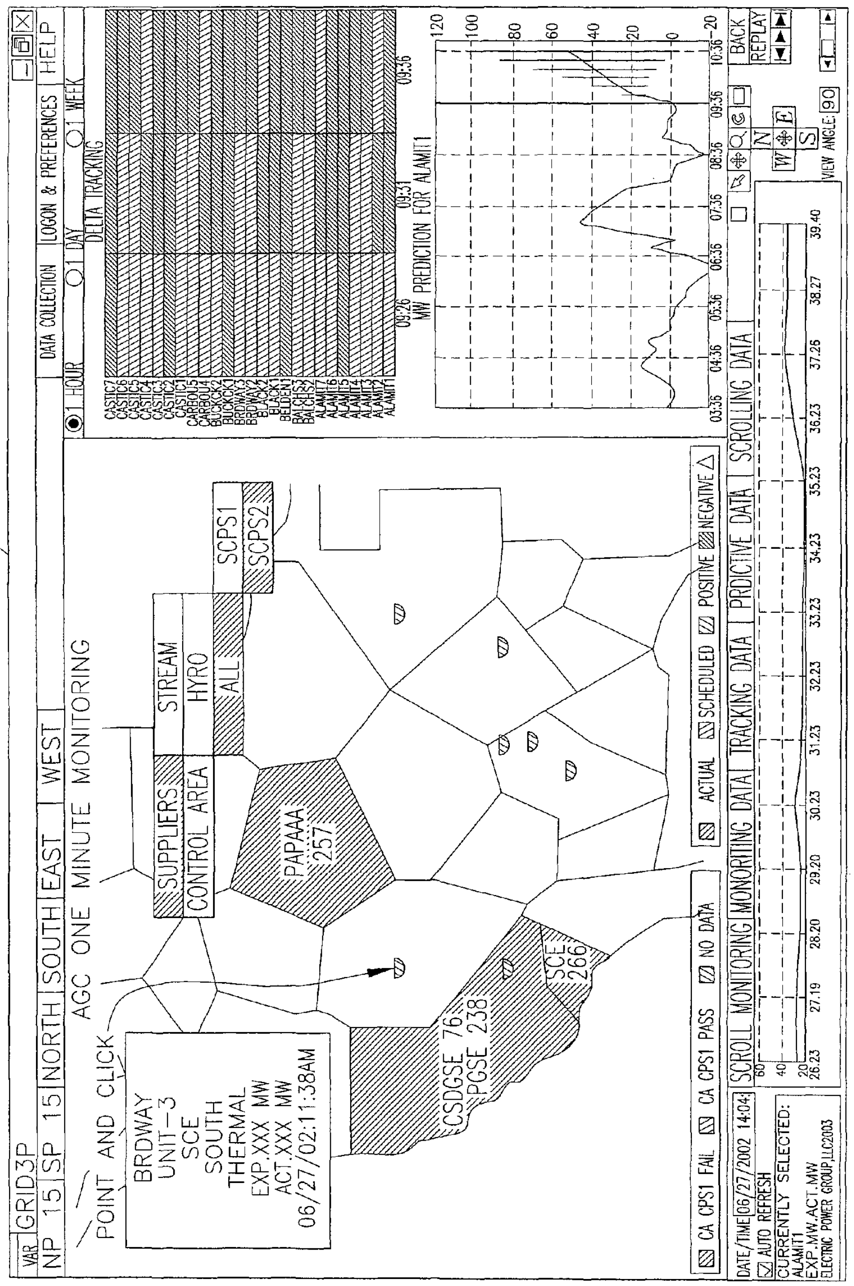
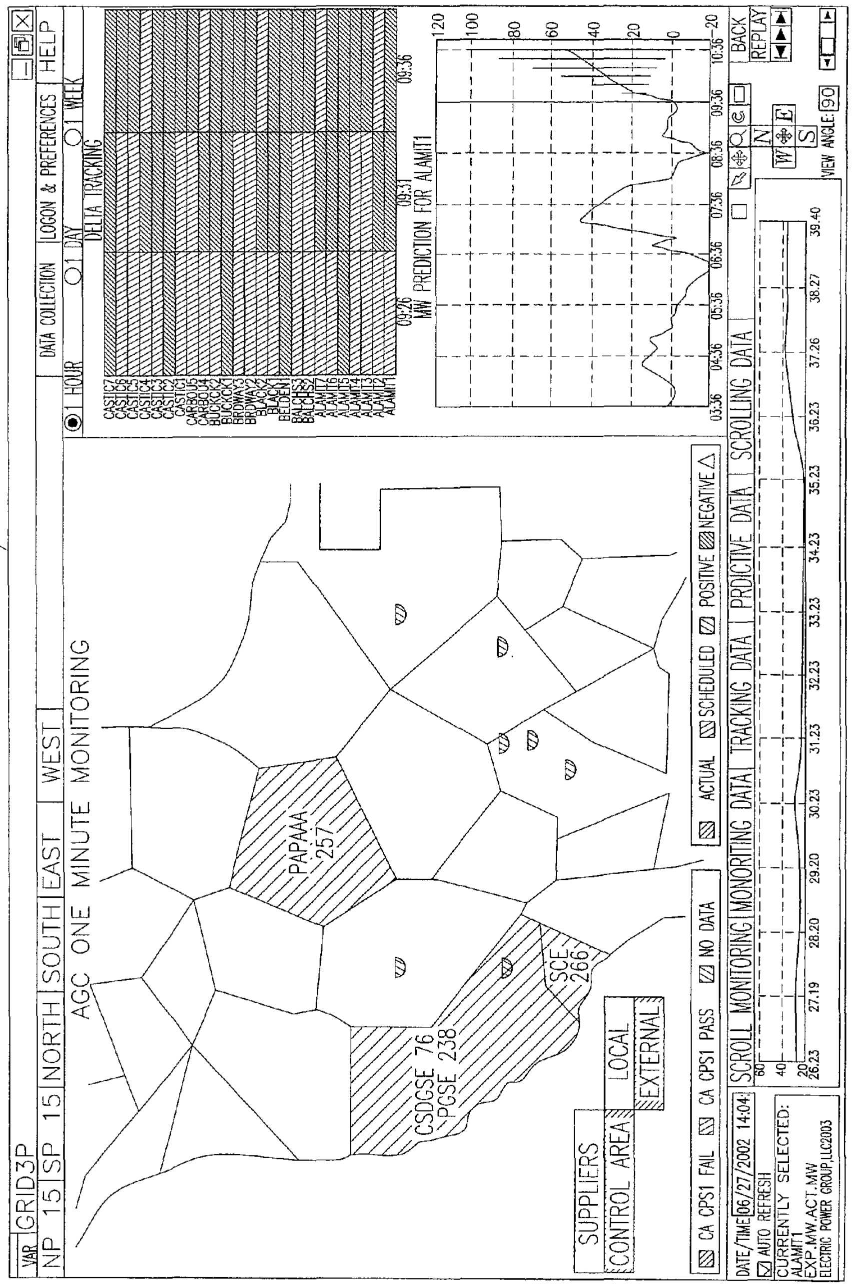

GRID3P
NP 15 SP 15 NORTH SOUTH EAST WEST
AGC ONE MINUTE MONITORING
DATA COLLECTION
LOGON & PREFERENCES
HELP
POINT AND CLICK
BRDWAY
UNIT-3
SCE
SOUTH
THERMAL
EXP.XXX MW
ACT.XXX MW
06/27/02:11:38AM
SUPPLIERS
CONTROL AREA
STREAM
HYRO
ALL
SCPS1
SCPS2
PAPAAA
257
CSDGSE 76
PGSE 238
SCE
266
1 HOUR
1 DAY
1 WEEK
DELTA TRACKING
MW PREDICTION FOR ALAMIT1
CA CPS1 FAIL
CA CPS1 PASS
NO DATA
ACTUAL
SCHEDULED
POSITIVE
NEGATIVE
SCROLL MONITORING
MONORITING DATA
TRACKING DATA
PRDICTIVE DATA
SCROLLING DATA
DATE/TIME 06/27/2002 14:04
AUTO REFRESH
CURRENTLY SELECTED:
ALAMIT1
EXP.MW,ACT.MW
ELECTRIC POWER GROUP,LLC2003
BACK
REPLAY
VIEW ANGLE 90

FIG. 36

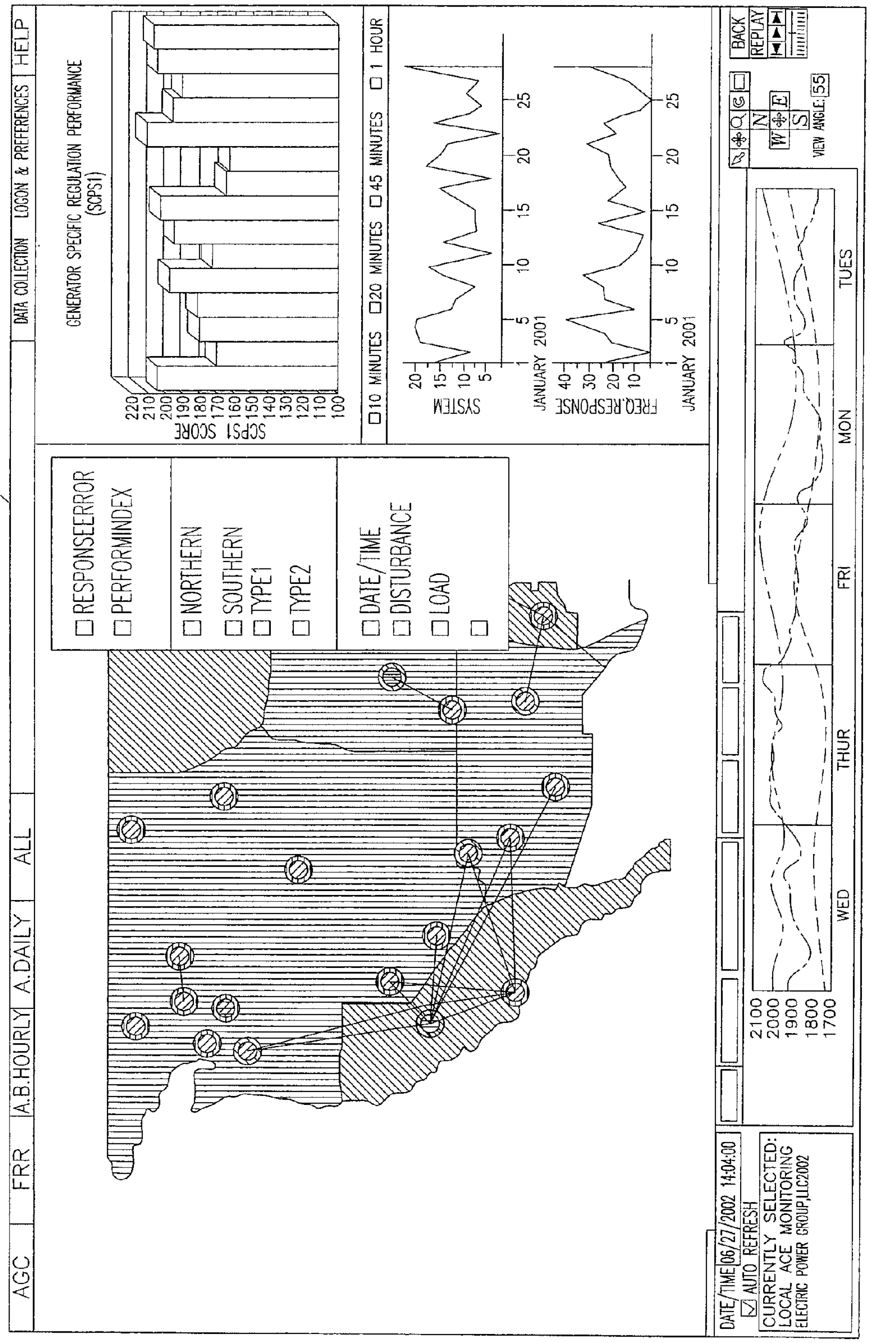
470



VAR GRID3P
NP 15 SP 15 NORTH SOUTH EAST WEST
AGC ONE MINUTE MONITORING
DATA COLLECTION
LOGON & PREFERENCES
HELP
1 HOUR
1 DAY
1 WEEK
DELTA TRACKING
MW PREDICTION FOR ALAMIT1
PAPAAA 257
CSDGSE 76
PGSE 238
SCE 266
SUPPLIERS
CONTROL AREA
LOCAL
EXTERNAL
CA CPS1 FAIL
CA CPS1 PASS
NO DATA
ACTUAL
SCHEDULED
POSITIVE
NEGATIVE
SCROLL MONITORING DATA
MONORITING DATA
TRACKING DATA
PRIDICTIVE DATA
SCROLLING DATA
DATE/TIME 06/27/2002 14:04
AUTO REFRESH
CURRENTLY SELECTED:
ALAMIT1
EXP.MW.ACT.MW
ELECTRIC POWER GROUP,LLC2003
BACK
REPLAY
VIEW ANGLE: 90

FIG. 37

480


AGC
FRR
A.B.HOURLY
A.DAILY
ALL
DATA COLLECTION
LOGON & PREFERENCES
HELP
RESPONSEERROR
PERFORMINDEX
NORTHERN
SOUTHERN
TYPE1
TYPE2
DATE/TIME
DISTURBANCE
LOAD
GENERATOR SPECIFIC REGULATION PERFORMANCE (SCPS1)
SCPS1 SCORE
10 MINUTES
20 MINUTES
45 MINUTES
1 HOUR
SYSTEM
JANUARY 2001
FREQ.RESPONSE
JANUARY 2001
DATE/TIME 06/27/2002 14:04:00
AUTO REFRESH
CURRENTLY SELECTED:
LOCAL ACE MONITORING
ELECTRIC POWER GROUP,LLC2002
WED
THUR
FRI
MON
TUES
BACK
REPLAY
VIEW ANGLE: 55

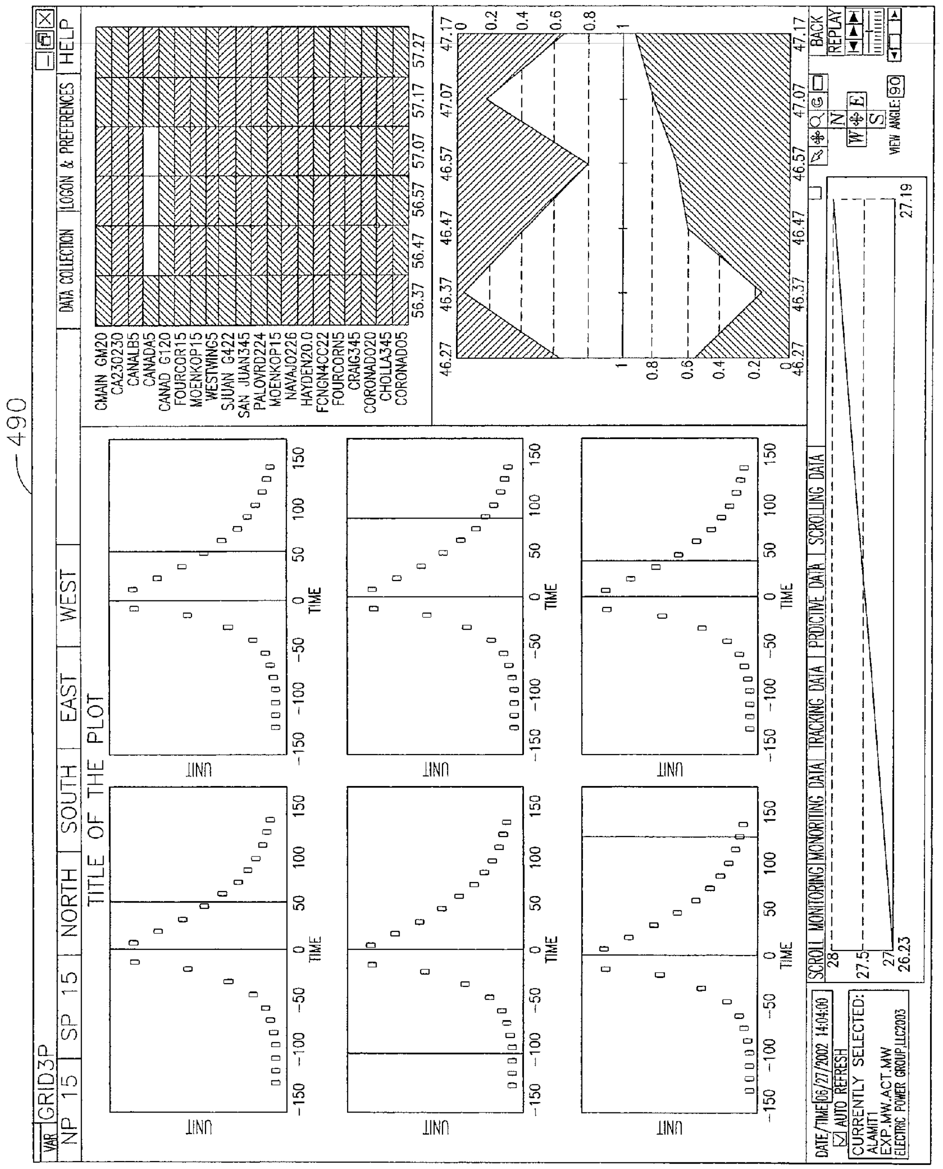

490
VAR
GRID3P
NP 15
SP 15
NORTH
SOUTH
EAST
WEST
DATA COLLECTION
LOGON & PREFERENCES
HELP
TITLE OF THE PLOT
UNIT
TIME
SCROLL MONITORING
MONORITING DATA
TRACKING DATA
PRDICIVE DATA
SCROLLING DATA
DATE/TIME 06/27/2002 14:04:00
AUTO REFRESH
CURRENTLY SELECTED:
ALAMIT
EXP.MW.ACT.MW
ELECTRIC POWER GROUP,LLC2003
BACK
REPLAY
VIEW ANGLE: 90

FIG. 38

WIDE-AREA, REAL-TIME MONITORING AND VISUALIZATION SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. application Ser. No. 11/764,145, filed Jun. 15, 2007, now U.S. Pat. No. 8,060,259, issued on Nov. 15, 2011, which is a continuation of U.S. application Ser. No. 10/914,789, filed Aug. 9, 2004, now U.S. Pat. No. 7,233,843, issued on Jun. 19, 2007, which claimed the benefit of U.S. Provisional Application Nos. 60/493,526, filed Aug. 8, 2003, and 60/527,099, filed Dec. 3, 2003, the disclosures of which are incorporated fully herein by reference.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

This invention was made partially with government support under Department of Energy Contract #DE-AC03-76SF00098, Subcontract #6508899. The Government has certain rights in this invention.

FIELD OF THE INVENTION

The present invention relates generally to a monitoring and management platform, and more particularly to a real-time performance monitoring and prediction system that has wide applicability to various industries and processes.

BACKGROUND

In various industries, the ability to monitor, track, predict and/or act in real-time is desirable. These industries include electric power, gas pipeline, water systems, transportation, chemicals and processes, infrastructure protection, security monitoring and others.

By way of example, in the electric power industry, power is typically supplied to customers in a four stage process of generation, transmission, distribution and end use. FIG. **1**A illustrates a typical process of generation, transmission and distribution of electricity. As illustrated in FIG. **1**A, the electricity is generated competitively by a number of power plants. The electricity is then transmitted through a number of transmission lines that are regulated by the Federal Energy Regulatory Commission (FERC). These transmission lines, which may be located in different states, are typically owned by the utility or transmission companies, and controlled by regional Independent System Operators (ISOs), Regional Transmission Organizations (RTOs) or utility companies that may be private or public. The generation and transmission of electricity are usually managed by regional entities that monitor the grid operations, market operations, security and other aspects of the electric power system.

The transmitted electricity is typically distributed through state or locally regulated distribution companies. The transmission and distribution systems utilize a number of devices for management and control of the electric system, including dynamic voltage support, remedial action schemes, capacitors, storage and flow control devices. The electricity is distributed to the customers as the end users, or consumers of electricity. Some of the customers may also have micro-grids of their own. The demand placed by these customers also needs to be managed.

Due to the enormous task at hand, there are a number of organizations responsible for overseeing these power generation, transmission and distribution activities. For example, there are over 3,000 utilities, thousands of generators, 22 Reliability Coordinators, and 153 Control Areas (CAs) in the United States for monitoring and control of generation, transmission and distribution of electricity. While all these different entities at various different levels are involved in generation, transmission and distribution of electricity as well as monitoring and control in a power grid, there is no single integrated system that can be used to monitor and manage the electric power grid in real-time across all of the different elements of the power system. For example, there is no information management system for the power grid, which is integrated across multiple business systems, companies and Control Areas to manage the security, timeliness, accuracy or accessibility of information for grid operations, reliability, market operations and system security. Analogous issues may be apparent in other industries.

SUMMARY

In an exemplary embodiment according to the present invention, a real-time performance monitoring, management and prediction platform is provided. Systems based on the platform may be used to manage processes in various industries, based on current monitoring tools as well as tools that are under development, for example, in smart, switchable networks. Systems based on the platform preferably include visualization features that enable managers and operators in various industries to: measure key system operating and market metrics; monitor and graphically represent system performance, including proximity to potential system faults; track, identify and save data on abnormal operating patterns; and predict system response in near real-time by means of simulations and predictive analysis.

In one exemplary application of the present invention, a power grid monitoring and management system is provided. The power grid monitoring and management system includes a technology platform for real-time performance monitoring application for the electric power grid. The power grid monitoring and management system in one exemplary embodiment may also be referred to as a Grid Real-Time Performance Monitoring and Prediction Platform (Grip-3PTM). The Grid-3P platform is designed to enable monitoring of a range of electric grid parameters, including metrics for reliability, markets, generation, transmission, operation, and security. The visualization features enable display of information geographically and graphically; in real time; and enables operators to define display levels—local or wide area, control area, interconnection or other user defined manner. This technology is being used to develop and implement real-time performance monitoring applications at Reliability Coordinator and Independent System Operator (ISO) locations, including the following applications: Area Control Error (ACE)-Frequency Real-Time Monitoring System; Control Area and Supplier's Performance for Automatic Generation Control and Frequency Response Services System; VAR-Voltage Management and Monitoring System; and Monitoring Applications based on Synchronized Phasor Measurements.

Examples of electric grid system components and metrics that could be monitored include electric interconnections, generators, voltage levels, frequency, market prices, congestion, market power metrics, demand forecasts, and other system components and metrics.

Another feature of the Grid-3P platform is the concept of multi-panel displays that allow: real-time monitoring of key metrics; display of history and performance tracking of key

metrics; performing sensitivity evaluations and assessments of key metrics under alternative scenarios, and developing predictions or near term forecasts of performance; and initiating actions, such as providing e-mail notification for alerting operators about abnormal conditions and the need to take action.

The power grid monitoring and management system may operate in a web environment, client-server, dedicated server, and/or secure proprietary network. In addition, the power grid monitoring and management system may allow interactive historical data collection and to present the collected data in tabular and/or specialized data-visuals. Further, the power grid monitoring and management system may be used to create interactive data reports from grid performance historical data saved in data-servers.

In an exemplary embodiment according to the present invention, a real-time performance monitoring system monitors an electric power grid having a plurality of grid portions, each said grid portion corresponding to one of a plurality of control areas. A monitor computer monitors at least one of reliability metrics, generation metrics, transmission metrics, suppliers metrics, grid infrastructure security metrics, and markets metrics for the electric power grid. A database stores the metrics being monitored by the monitor computer, and at least one display computer has a monitor for displaying a visualization of the metrics being monitored by the monitor computer. Said at least one display computer in one said control area enables an operator to monitor a said grid portion corresponding to a different said control area.

In another exemplary embodiment according to the present invention, a method of monitoring a performance of an electric power grid in substantially real-time is provided. The electric power grid has a plurality of grid portions, each said grid portion corresponding to one of a plurality of control areas. A monitor computer is used to monitor at least one of reliability metrics, generation metrics, transmission metrics, suppliers metrics, grid infrastructure security metrics, and markets metrics for the electric power grid. The metrics being monitored by the monitor computer is stored in a database, and a visualization of the metrics being monitored by the monitor computer is displayed on a monitor of at least one display computer. Said at least one display computer in one said control area enables an operator to monitor a said grid portion corresponding to a different said control area.

These and other aspects of the invention will be more readily comprehended in view of the discussion herein and accompanying drawings, in which like reference numerals designate like elements.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A illustrates a typical process of generation, transmission and distribution of electricity;

FIG. **1**B illustrates a process of generation, transmission and distribution of electricity, and a set of exemplary information management requirements according to the present invention;

FIG. **2**A is a block diagram that illustrates an exemplary performance management strategy according to the present invention;

FIG. **2**B illustrates a process of controlling generation, transmission and distribution of electricity with an integration of real time wide area monitoring for reliability management;

FIG. **2**C illustrates an infrastructure for a wide area reliability monitoring center (WARMC) of FIG. **2**B;

FIG. **3** is a block diagram that illustrates an exemplary performance management process according to the present invention;

FIG. **4** is a block diagram that illustrates an exemplary multi-layered platform for performance monitoring and management according to the present invention;

FIG. **5** is a block diagram that illustrates the integration into power generation, transmission and distribution of the power grid monitoring and management system in an exemplary embodiment according to the present invention;

FIG. **6** illustrates a power grid monitoring and management system of FIG. **5** and includes the major reliability applications for real-time reliability monitoring for NERC Reliability Coordinators and Control Area Dispatchers;

FIG. **7** illustrates an application of the power grid monitoring and management system for utilization by RTOs to monitor markets, operations, security, and other functions;

FIG. **8** illustrates an application of the power grid monitoring and management system in an exemplary embodiment according to the present invention;

FIG. **9** is a local area network (LAN) based hardware and software architecture for the power grid monitoring and management system in an exemplary embodiment according to the present invention;

FIG. **10** is a web-based hardware and software architecture for the power grid monitoring and management system in another exemplary embodiment according to the present invention;

FIG. **11** illustrates the architecture of an ACE-Frequency real-time monitoring application using the power grid monitoring and management system in an exemplary embodiment according to the present invention;

FIG. **12** illustrates five major functional components of the NERC ACE-Frequency real-time monitoring system in an exemplary embodiment according to the present invention;

FIG. **13** illustrates reliability functional levels and visualization hierarchy in an exemplary embodiment according to the present invention;

FIG. **14** illustrates an integrated visualization model in an exemplary embodiment according to the present invention;

FIG. **15** illustrates an ACE-Frequency real-time monitoring architecture of the power grid monitoring and management system in an exemplary embodiment according to the present invention;

FIG. **16** is a screen shot that illustrates a multiple view architecture of a display of the power grid monitoring and management system in an exemplary embodiment according to the present invention;

FIG. **17** is screen shot of a Cave diagram that represents a Frequency/ACE diagram in an exemplary embodiment according to the present invention;

FIG. **18** is a screen shot of a default display for a Reliability Authority in an exemplary embodiment according to the present invention;

FIG. **19** is a screen shot of an Interconnect-Epsilon map in a three-panel display in an exemplary embodiment according to the present invention;

FIG. **20** is a screen shot of a local view for a Control Area map in an exemplary embodiment according to the present invention;

FIG. **21** is a screen shot of a current Control Area map for a selected Control Area in an exemplary embodiment according to the present invention;

FIG. **22** is screen shot of a CPS map in an exemplary embodiment according to the present invention;

FIG. **23** is a screen shot of a three-panel view in an exemplary embodiment according to the present invention;

FIG. **24** is a screen shot of a data collection tool in an exemplary embodiment according to the present invention;

FIG. **25** is a screen shot of charts generated using the data collected using the data collection tool of FIG. **24**.

FIG. **26** illustrates utilization of NERC ACE-Frequency monitoring in an exemplary embodiment according to the present invention;

FIG. **27** illustrates a screen shot of a supplier-Control Area performance for AGC and frequency response application in an exemplary embodiment according to the present invention;

FIG. **28** illustrates a market monitoring system in the power grid monitoring and management system in an exemplary embodiment according to the present invention;

FIG. **29** illustrates a screen shot of a market monitoring application in an exemplary embodiment according to the present invention;

FIG. **30** illustrates a security center monitoring system in an exemplary embodiment according to the present invention;

FIG. **31** illustrates a screen shot of a real-time security monitoring application of the power grid monitoring and management system in an exemplary embodiment according to the present invention;

FIG. **32** is a block diagram of a NERC reliability functional model in an exemplary embodiment according to the present invention;

FIG. **33** illustrates a Control Area and suppliers performance monitoring and prediction platform for AGC, FRR and regulation A.S. in an exemplary embodiment according to the present invention;

FIG. **34** is a screen shot of a panel view for control area and suppliers performance for, AGC, FRR and A.S. in an exemplary embodiment according to the present invention;

FIG. **35** is a screen shot of a panel view for Control Area and generator response to AGC in an exemplary embodiment according to the present invention;

FIG. **36** is a screen shot for a panel view for Control Area and generators response to frequency response in an exemplary embodiment according to the present invention;

FIG. **37** is a screen shot for a panel view for Control Area and generators response to regulation A.S. in an exemplary embodiment according to the present invention; and

FIG. **38** is a screen shot of a common view for performance of AGC, FRR and X-minutes ancillary services regulation (default 10 minutes) in an exemplary embodiment according to the present invention.

DETAILED DESCRIPTION

Referring to FIG. **1**B, a set of exemplary information management requirements for the present invention may include: integration across multiple business system, companies and CAs; and information security, timeliness, accuracy, and accessibility.

Referring to FIG. **2**A, an exemplary performance management strategy according to the present invention contemplates identification of key metrics **1**, monitoring **2**, analysis **3** and assessment **4**. Utilizing the platform and system described herein, the strategy may be beneficially employed for a wide variety of industries and processes, including without limitation, electric power, gas pipeline, water systems, transportation, chemicals and processes, infrastructure protection, security monitoring and others.

According to an exemplary embodiment of the present invention, a wide area reliability monitoring center (WARMC) provides a visibility to system conditions across

control area boundaries, improves reliability management capability, and/or prevents future blackouts. The WARMC provides Reliability Coordinator and Control Area operators with a wide area perspective of grid operations real-time, beyond its immediate area of responsibility. The WARMC may additionally have other functions and applications including new functions and applications to be developed, and may serve as a center that supports grid reliability for an entire Interconnection (e.g., Eastern Interconnection (EI)), for example.

In recent years, the functional disaggregation of electric utilities has resulted in gaps in the overall grid reliability management in terms of who (Control Areas, Reliability Coordinators, ISO/RTOs) has visibility of key system parameters with apparently no one having the full picture. By way of example, blackouts, such as the Aug. 14, 2003 blackout in the United States and Canada, may have been caused by a lack of situational awareness caused by inadequate reliability tools and backup capabilities. Further, deficiencies in control area and reliability coordinator capabilities to perform assigned reliability functions may also have led to blackouts.

During the blackouts, the operators may have been unaware of the vulnerability of the system to the next contingency. The reasons for this may include one or more of inaccurate modeling for simulation, no visibility of the loss of key transmission elements, no operator monitoring of stability measures (e.g., reactive reserve margin, power transfer angle), and no reassessment of system conditions following the loss of an element and readjustment of safe limits. The wide area real time monitoring for reliability management of the present invention is adapted to the changing industry structure and helps to reduce or prevent blackouts.

The wide area reliability monitoring functions of the present invention may be integrated with existing operations and provide system operators and Reliability Coordinators with tools for monitoring not only their own Control Areas but also adjacent Control Areas and the Interconnection. The integration of the real time wide area monitoring for reliability management with existing control, communications, and monitoring infrastructure is shown in FIG. **2**B, for example.

As shown in FIG. **2**B, operators currently have access to databases or platforms and perform control and monitoring functions at three levels: 1) Level 1—local power plant controls using plant data to control local generation of power; 2) Level 2—SCADA (regional control center) using generation, transmission and substations data to control regional and local substations, which involves controlling local load-generation balance-AGC and local grid switching in real-time; and 3) Level 3—EMS for Control Area operations including use of state estimation, grid security analysis and security constrained dispatch, using grid voltage and interconnection frequency-ACE data.

The WARMC according to an exemplary embodiment of the present invention introduces a new Level 4, which utilizes existing SCADA data as well as time synchronized data from phasors or other sources and/or other new data sources for wide area monitoring. As shown in FIG. **2**B, the WARMC provides one or more of the following applications: 1) Wide-Area Load-Generation Balance-ACE-Frequency real-time monitoring; 2) Wide-Area Grid Dynamics and Reliability monitoring—RTDMS; 3) real time operations management information; and 4) state estimation using phasors. The WARMC may have one or more of other monitoring, management information reporting, state estimation, and controls applications.

The WARMC provides a wide area monitoring and reliability management capability that extends across control

area boundaries. The WARMC may include one or more of monitoring applications, connectivity with other Interconnection entities, improved phasor and PDC hardware, and secure and redundant communication networks for data exchange. The WARMC may enable RTOs, Independent Transmission Owners (TOs), North American Electrical Reliability Council (NERC), other Interconnection stake holders, and/or the like to monitor key reliability metrics impacting their respective areas and provide the capability to monitor and manage an entire Interconnection grid (e.g., Eastern Interconnection grid).

By way of example, the WARMC may provide one or more of the following functions or capabilities: 1) wide area system visibility; 2) data connectivity to key RTOs and reliability management organizations; 3) time synchronized data in real time; 4) monitoring of key grid reliability metrics for an Interconnection (e.g., Eastern Interconnection); 5) real time performance monitoring and reporting; 6) enhanced state estimation; 7) fast simulation and modeling; and 7) smart grid with automated controls.

The WARMC may be fully automated, such that it will compile critical high speed data, process it, provide Interconnection (e.g., EI) reliability authorities with reliability information on the health of the Interconnection and, as required, may enable/disable remedial actions schemes (RAS) and may re-configure the grid. The WARMC may be linked through secure, reliable and redundant communications to key RTOs, transmission owners, utilities, and control area operators. The conceptual framework for an WARMC infrastructure is shown in FIG. **2**C. As can be seen in FIG. **2**C, the WARMC **2'** is coupled via a wide area network to a number of RTOs 1-n, one or more super computers and a number of TOs 1-n.

The WARMC should have access to critical real-time and historical operating data from all regions of an Interconnection (e.g., EI) to perform one or more of real time monitoring, post disturbance assessments, analyses for future enhancements and modeling to support a smart grid with automatic controls.

By way of example, the WARMC may have the necessary infrastructure, support systems and data to provide meaningful information for TOs, RTOs, and Reliability Coordinators to effectively perform one or more of the following: 1) validate the next-days operating plan and ensure the bulk power system can be operated reliably in anticipated normal and contingency conditions; 2) perform wide area monitoring, tracking and management of real-time grid operations; 3) anticipate and respond to changing conditions and flows; and 4) simulate "what if" scenarios.

The WARMC may also have capabilities to perform post disturbance assessment functions including one or more of: 1) evaluating compliance with NERC/Reliability Regional Standards; 2) Providing feedback to the pre-planning (day-ahead) process; 3) and validating model representation of expected grid performance. The WARMC may also define enhancements to the grid by, for example, assessing constraints, bottlenecks and vulnerabilities that will have a negative impact on grid reliability.

Referring now to FIG. **3**, the identification and use of key metrics **1** involves the evaluation and development of standards that may be quantified and measured. Metrics exist for a particular industry and different areas of a particular industry. For example, there may be metrics relating to reliability and others relating to markets, in which the metrics for each subcategory may overlap. Monitoring **2** contemplates the use of tools, whether they exist now or become available in the future, for tracking actual performance in real-time with a goal, among others, of looking for early warning signs. Analysis **3** contemplates converting archived monitoring information into meaningful information. Such data includes without limitation, risk analysis, grid data, depending on the particular industry or process being monitored, market data, historical data, and key reliability indicators. Assessment **4** contemplates the determination of impacts on reliability, markets, efficiency and asset utilization. Examples, which may change depending on the particular industry or process being assessed, include risk assessment, grid reliability and market efficiency. The desired assessment may modify the parameters or metrics that are monitored to achieve the desired results.

In one exemplary application of the present invention, the Grid-3P system, based upon a real-time performance and prediction platform for power grid monitoring and management, includes monitoring of generation/demand, grid data and markets as more particularly set forth herein. By way of example, the WARMC discussed above may be based on the Grid-3P system.

The reliability applications may include one or more of real-time monitoring of voltage/volt-ampere reactive (VAR), Area Control Error (ACE)/Frequency, Area Interchange Error (AIE)/Schedules, and/or other grid attributes and performance metrics. The generation applications may include suppliers and Control Area responses to Automatic Generation Control (AGC), frequency response and ancillary services, ramping response, and/or other metrics. The grid infrastructure security application may include one or more of system vulnerability, exposure (in terms of population, cities, etc.) and/or other metrics. Market applications may include one or more of generation market power, price spikes and/or other metrics.

In another exemplary embodiment according to the present invention, the power grid monitoring and management system enables one or more of real-time monitoring, historical tracking, prediction (near real-time forecasting up to 6-hours or what if sensitivity analysis), and actions (notification, system re-dispatch, mitigation measures, etc.) In other embodiments, the forecasting may be performed for more than six (6) hours.

In still another exemplary embodiment according to the present invention, the power grid monitoring and management system provides displays that utilize data and information that are user-defined and may or may not be algorithmically correlated with other displays.

In a further exemplary embodiment according to the present invention, data monitoring may be in real-time or near real-time for monitoring purposes. For example, real-time may be 1-4 seconds snapshot or up to 5 to 10 minute snap shots.

In yet further exemplary embodiment according to the present invention, the power grid monitoring and management system may be utilized to create a standalone monitoring system or be integrated with Security Control and Data Acquisition (SCADA), Energy Management System (EMS), PMUs-PDCs (phasor measurement units-phasor data concentrators) or other control power systems. The SCADA is a system of remote control and telemetry used to monitor and control transmission systems. In other words, the power grid monitoring and management system utilizes data from or is integrated with at least one of SCADA, EMS, PMUs-PDCs and another control power system.

In a still further exemplary embodiment according to the present invention, the power grid monitoring and management system may be used with standard monitoring and control applications and/or end-user defined customer applications.

Referring to FIG. **4**, the platform incorporates a multi-layered approach to performance monitoring and management. Layer **1** (**5**), the data layer, incorporates conventional relational databases with time series capability (for real-time monitoring and synchronization), a data archival system and/or information management with data mining capabilities. Further, layer **1** includes web-based data communications, COM+ databases and data conversion APIs. One purpose of Layer **1** is to read data from conventional databases that gather the data in real-time, and to communicate the data in real-time.

Layer **2** (**6**), which uses analytical algorithms for massaging the data accumulated in the databases of layer **1**, includes two sublayers (**6***a* and **6***b*), one focusing on optimization, forecasting, statistics and probabilistic technologies, and other on real-time performance monitoring. Within layer **2***a* (**6***a*), the platform includes tools and algorithms for linear and non-linear optimizing, self-organize maps and generic algorithms, forecasting, probabilistic analysis and risk assessment, multivariate statistical assessment, performance metrics definition and assessment, and other analytical technologies that may become available. Within layer **2***b* (**6***b*), the system includes real-time ACE-frequency monitoring, real-time suppliers control area performance for AGC and FR, voltage VAR management, dynamics monitoring using phasor measurements and other applications that may become available.

Dynamic monitoring using phasor analysis is particularly important in systems where monitoring data at subtransient levels may be useful. By way of example, existing power systems have dynamic behavior on the order of milliseconds. Traditional sampling, however, occurred at 4 second intervals. New monitoring techniques enable sampling up to 20-30 times per seconds or more. The present system, using dynamic phasor analysis, is capable of analyzing data gathered at subtransient intervals, synchronizing the data to other system parameters based on the time series capability of layer **1**, and presenting the data for visualization in an organized and logical manner in layer **3**.

Deployment of phasor technology over wide areas is useful for supporting reliable region-wide and inter-regional transfers of electricity without facing transient reliability conditions. An objective of real time dynamics performance monitoring using phasors is to provide grid operators with phasor data in real-time so that they can obtain a more accurate picture of the actual health of the grid. The information allows them to verify that they are operating within the transient boundaries of safe operation, as determined by off-line planning studies, as well as whether the operating guidelines provided by these studies remains valid. Such real-time data provided by phasor or other real time monitoring technologies also supports creation of an automatic, switchable grid that can sense and respond automatically to warning signs of grid emergencies.

Layer **3** (**7**) uses a novel visualization system that includes a multi-layer view for geo-graphic, wide and local areas. Such a system that allows local or wide area visualization provides significant benefits for understanding the effect of national or neighboring areas on local areas or interest, such as local utilities. In yet another exemplary embodiment according to the present invention, the power grid monitoring and management system is flexible to include one or more dynamic geographic displays and several data or text panels in one or more windows for monitoring, tracking, prediction, and actions or mitigations. Further, by synchronizing data from various sources and presenting it as such, the system enables the user to visualize a wide array of phenomena that may have an impact at a given time on the area or process of interest. The system further provides auto-onelines for tracing the path of electricity, water or other resources through the system. These diagrams allow the user to visualize potential sources of faults or other aspects of the system that may lead to system faults, and to take appropriate action prior to such a fault.

In an exemplary application of the present invention, new methods, tools and technologies are provided to protect and enhance the reliability of the U.S. electric power system by providing a real-time performance monitoring platform. The power grid monitoring and management system of the present invention, for example, includes a platform for performing real-time monitoring of frequency of electricity, customer usage ("load") and/or the amount of power being generated ("generation"). What may also be monitored is the difference between load and generation, and its effect on the frequency of the system.

In the exemplary embodiment, the system includes a series of modular, but integrated, computer-based, real-time data-to-information engines and graphic-geographic visualization tools that have served as a platform to develop reliability applications to assist operating authorities, business entities or companies, e.g., Independent System Operators (ISOs), Regional Transmission Organizations (RTOs), Reliability Coordinators and Control Area Dispatchers in their management of grid reliability, which may use different business systems. For North American Electric Reliability Council (NERC), these applications include the ACE-Frequency and AIE real-time monitoring systems.

The ACE may be defined as an instantaneous difference between net actual and scheduled interchange (i.e., energy transfers that cross control area boundaries), taking into account the effects of frequency bias including a correction for meter error. An AIE survey may be used to determine the Control Areas' interchange error(s) due to equipment failures or improper scheduling operations or improper AGC performance, where AGC may refer to equipment that automatically adjusts a Control Area's generation from a central location to maintain its interchange schedule plus frequency bias. The ACE and AIE monitoring systems together may be referred to as a Compliance Monitoring System (CMS). The CMS may also include one or more other components.

The ACE-Frequency and AIE real-time monitoring system applications enable NERC Reliability Coordinators to monitor ACE-Frequency performance and compliance with performance operational guides within their jurisdictions, and also allow NERC staff and subcommittees to analyze and assess control data to improve reliability tracking and performance. The ACE-Frequency real-time monitoring system, for example, translates raw operational control data into meaningful operations performance information for end users. Should an abnormal interconnection frequency occur, a real-time interconnection abnormal frequency notification (AFN) may be automatically issued via e-mail and/or beepers describing the date, time and magnitude of the frequency abnormality to specific operational authorities, NERC Resource Subcommittee members and NERC Staff.

The notification recipients using the ACE-Frequency monitoring system functionality can quickly assess the abnormality's root cause by drilling down from wide-area to local-area visualization displays that include appropriate information and analysis graphs to easily identify and assess those Control Area(s) out of compliance and potential originators of the notified interconnection frequency abnormality. A Control Area may be defined as an electrical system bounded by interconnection (tie-line) metering and telemetry. The Control Area controls generation directly to main-

tain its interchange schedule with other Control Areas and contributes to frequency regulation of the Interconnection. Interconnection may refer to any one of the bulk electric system networks in North America: Eastern, Western and ERCOT, and may also refer to Quebec electric system network. When not capitalized, it may also refer to facilities that connect two systems or Control Areas.

FIG. **5** is a block diagram that illustrates the integration into power generation, transmission and distribution of the power grid monitoring and management system in an exemplary embodiment according to the present invention. The top part of FIG. **5** illustrates that the current business model is segmented into generation, transmission, distribution, markets and security. It can be seen here that the vertically integrated business model historically used by utilities has evolved to a segmented market dispersed among separate entities.

The power grid monitoring and management system has been developed to serve as the base for the development of reliability applications for real-time monitoring, tracking and prediction for the reliability performance of Control Areas, generation, grid, markets, and security. Control Area's ACE, interconnection's frequency and interchange data on top of the power grid monitoring and management system provide a common tool to be utilized by NERC Reliability Coordinators, Control Area Dispatchers, and Transmission Dispatchers. The bottom of FIG. **2** also shows that reliability applications developed using the power grid monitoring and management system may serve as complement for traditional SCADA/EMS systems and for the periodic reporting requested by NERC for post performance.

As can be seen in FIG. **5**, various different data are provided by generation **10**, utilities **20** (transmission **12** and substations **14**), market **16** and security **18**. These data, such as generation data, grid data, market data and performance data are provided to one or more various different organizations **22** such as, for example, ISOs, RTOs, transmission companies, Control Areas and the like.

One or more of these organizations perform real-time operations **24** such as scheduling, dispatching, system security, ancillary services and the like. Also, one or more of these organizations perform assessment and reporting **26** such as reports to reliability authorities such as ISOs, RTOs, FERC/PUCs and NERC.

As illustrated in FIG. **5**, the power grid monitoring and management system in the described exemplary embodiment provides an infrastructure for integrating the monitoring and control of real-time operations, assessment and reporting provided by various different entities using data provided by still other various different organizations.

FIG. **6**, for example, shows an expansion of the power grid monitoring and management system **28** from FIG. **2** and includes the major reliability applications for real-time reliability monitoring for NERC Reliability Coordinators and Control Area Dispatchers. The top part FIG. **3** shows the applications target for Reliability Coordinators, ACE-frequency, AIE and control performance standards (CPS). The bottom part of FIG. **6** shows the applications target to Control Area Dispatchers, performance compliance of Control Areas, suppliers to AGC, FRR and ancillary services markets.

As can be seen in box **30**, NERC Reliability Coordinators monitor several requirements, including ACE-Frequency, to maintain and enhance the reliability of their jurisdictions. The ACE-Frequency Monitoring System, shown in the upper applications box (Reliability Region Performance Monitoring Platform) **34**, provides applications for each Coordinator within each of their Reliability Regions. Reliability Coordinators utilize those applications to monitor performance and compliance within their Regions and notify the appropriate Control Area Dispatchers as abnormalities occur. Control Area Dispatchers pinpoint problem sources by monitoring the response performance of their Control Area and suppliers to AGC monitoring system, frequency response resources and ancillary services.

For example, in one exemplary embodiment, the power grid monitoring and management system may be described in reference to performance monitoring, tracking and short term prediction of California Independent System Operator (CAISO) Control Area and suppliers response to AGC, frequency response reserves (FRR) and ancillary services application as shown in box **36** (Control Area Performance Monitoring Platform) to support Control Area Dispatchers Monitoring Requirements (**32**). This application represents further progress towards grid reliability technologies and management tools that present real-time performance, tracking and predictive information across several spheres of grid operating and reliability concerns.

FIG. **7** illustrates an application of the power grid monitoring and management system **40** in an exemplary embodiment according to the present invention. The power grid monitoring and management system includes a platform to support RTO functions (**42**) such as markets, operations, security and reliability monitoring.

FIG. **8** illustrates functions of the power grid monitoring and management system **50** in an exemplary embodiment according to the present invention. The power grid monitoring and management system **50** includes a platform for performing one or more of real-time performance monitoring **52**, historical performance tracking **54**, sensitivities and short term prediction **56**, and action & simulations for reliability and markets **58**.

As part of the real-time performance monitoring **52**, the power grid monitoring and management system may monitor one or more of voltage/VAR, ACE-Frequency, transmission congestion, generator performance for AGC and frequency response and market prices/spikes.

For historical performance tracking **54**, the power grid monitoring and management system may track one or more of Interconnection, Generator, Region/Zone/Substation as well as market.

As part of sensitivities and short term prediction **56**, the power grid monitoring and management system may predict/handle one or more of system demand, generator response, voltage sensitivities, distance from collapse and short term predictions.

The actions and simulations **58** performed by the power grid monitoring and management system may include one or more of notifications, reserves & ancillary services, capacitor dispatch, generation re-dispatch, VAR management and automatic mitigation.

FIG. **9** is a local area network (LAN) **100** based hardware and software architecture for the power grid monitoring and management system in an exemplary embodiment according to the present invention. The architecture includes a number of clients **114**, **124** that interface with a server **110** over the LAN **100**. The server and clients, for example, may be COM+ server and clients, and the communications may take place using XML language.

Each client **114**, **124** interfaces with the power grid monitoring and management system client **116** and **126**, respectively. The display of the power grid monitoring and management system **118** and **128** are used to provide visual indication of monitoring and tracking to the user.

The server **110** is coupled to a power grid monitoring and management system database **104**, for example, over an

OLEDB connection. The server **110** is also connected to a power grid monitoring and management system application server **102** and a client **108**. The communication between the server **110** and the client **108**, for example, is performed using XML language. Further, the client **108** communicates with one or more monitoring applications **106** using the XML language. The one or more monitoring applications **106** also interface with the power grid monitoring and management system application server **102**. The monitoring applications are connected over OLEDB connection and/or other data base connections to customer proprietary databases or data platforms **112**. The customer proprietary database or data platform **112** may include one or more of SCADA (Supervisory Content and Data Acquisition) database, market database, PI database and Phasor Data database. The LAN-based architecture may have different configurations in other embodiments.

FIG. **10** is a web-based hardware and software architecture for the power grid monitoring and management system in another exemplary embodiment according to the present invention. On the power grid monitoring and management system application server side, the configuration is identical to that of the LAN-based hardware and software architecture. The server **110**, however, communicates with another client (which may be a COM+ client) **142** using the XML language. The client **142** is coupled with an Internet Information Server (IIS) **140**. A power grid monitoring and management system web server **144** also communicates with the client **142** and the IIS **140**. The IIS **140** communicates over the Internet **150** using XML language and Simple Object Application Protocol (SOAP) protocol with the visualization programs **152** and **156**, respectively, for visual communication with users on web clients **154** and **158**, respectively. The web-based architecture may also have different configurations in other embodiments.

For example, in both the architectures of FIGS. **9** and **10**, only two clients are shown on the client side. In practice, however, there may be more than two clients. Further, the power grid monitoring and management system application server **102** may be coupled to both the LAN-based clients and web-based clients over the LAN and the Internet, respectively. Further, the Internet may be replaced or complemented by an Intranet or any other similar proprietary or non-proprietary networks.

FIG. **11** illustrates the architecture of an ACE-Frequency real-time monitoring application **160** using the power grid monitoring and management system in an exemplary embodiment according to the present invention. The ACE-Frequency monitoring system receives ACE and frequency data from the nation's Control Areas (Data Collection **162**), calculates performance parameters (e.g., reliability compliance parameters **170**) for each reliability jurisdiction and compares those performance parameters to NERC reliability compliance guides (Standards & Algorithms **166**). The results of these comparisons are then displayed graphically and (Visualization **164**) on a geographical map (Geography **168**) for use by each of the Reliability Organization from each of the layers, depicted in the lower, right pyramid **172**. The tiers of the pyramid comprise the control areas, reliability coordinators, reliability transmission organizations, reliability regions, and Interconnections.

FIG. **12** illustrates five major functional components of the NERC ACE-Frequency real-time monitoring system **180** in an exemplary embodiment according to the present invention: Local Monitoring **182**, Global Monitoring **184**, Abnormal Frequency Notification (AFN) **186**, Interactive Data Collection (IDC) **188** and Unavailable Data Reporting (UDR) **190**. Following are description of each one of the major functional components.

The first is the Local Monitoring Geographic-Graphic Visualization **182**. In the described exemplary embodiment, most of the ACE-Frequency visualization is geographic-graphic oriented and covers different time windows from current time to 30-days. The local-visualization option covers from current time to 1-hour, and it offers to end users three different views of Control Area ACE and Interconnection frequency data displayable in the three-panel window visualization.

The second is the Global Monitoring Geographic-Graphic Visualization **184**. In the described exemplary embodiment, this option uses the Epsilon performance parameter as an indicator of the frequency performance for each of the interconnections. For example, it shows the performance parameter for two time windows, 6-hours and 30-days. It also uses a power grid monitoring and management system three-panel window visualization as will be described below.

The third is the AFN **186**. The real-time AFN is a real-time monitoring component of the ACE-Frequency Monitoring System. The AFN is designed for real-time monitoring of abnormal interconnection frequencies, and to automatically issue e-mails to specific NERC Resources Subcommittee members and NERC staff when predefined abnormal frequency performance criteria are met. E-mail recipients may, for example, use the ACE-Frequency monitoring system capabilities to assess root causes of the abnormal frequencies when notified. The input data to the AFN may be provided by Control Areas to NERC over a secure connection using NERCnet, XML, and/or SOAP technologies.

The fourth is the IDC function **188**. Via the IDC functionality, NERC subcommittees, NERC staff, and operating engineers can interactively define the historical window of time and the specific control-performance parameter they need to analyze and assess frequent disturbances. Once data is collected from the NERC data server, the users can use equivalent reliability coordinator visualization and/or save the data in comma-delimited files.

The fifth is the DRG function. The DRG offers the capability to interactively identify and report Control Area data transfer performance. Users can select hourly, daily, weekly, and/or monthly reports and select the specific data they want to assess for availability.

It has been demonstrated by Control Area Dispatchers that the more effective operational displays are those that follow a hierarchical approach to present operational data for current time and other key windows of time. The power grid monitoring and management system visualization model in an exemplary embodiment of the present invention encompasses displays at high and low levels to meet the varying needs of different reliability application users. Thus, in the described exemplary embodiment, monitoring applications are developed for wide-area and local area users using the power grid monitoring and management system.

FIG. **13** illustrates reliability functional levels and visualization hierarchy in an exemplary embodiment according to the present invention, and FIG. **14** illustrates an integrated visualization model in an exemplary embodiment according to the present invention.

The hierarchal structure in FIG. **13** shows that it is desirable for the Reliability Coordinators to have a wide-area view of their jurisdictions for reliability compliance monitoring **192**. Also, it is desirable for the ISOs and RTOs to have the ability to assess performance and trends (**194**) of their Control Areas. In turn, it is desirable for Control Areas to have local area

information **196** to pinpoint specific suppliers reliability performance issues. The ACE-Frequency tool allows Reliability Coordinators to monitor ACE-Frequency performance and compliance for each of their jurisdictions using wide-control-area graphic-geographic visualization.

For the definition and design of the ACE-Frequency graphic-geographic visuals for each of the visualization layers shown in FIG. **13**, the data collection **200**, computational and display (or visualization) models **202**, **204** from the power grid monitoring and management system shown in the first three vertical segments on FIG. **14** may be used. For the NERC ACE-Frequency real-time monitoring system, about 123 Control Areas transmit ACE and frequency data to a data server located at NERC (data collection).

The data is processed and performance parameters are calculated in the computational engines (computational model) of the power grid monitoring and management system. The design and deployment of each of the displays follows the three steps (i.e., human factors, user interaction and composition) illustrated in the display model section **204** on FIG. **14**.

FIG. **15** illustrates an ACE-frequency real-time monitoring architecture of the power grid monitoring and management system in an exemplary embodiment according to the present invention. For example, input data is provided by Control Areas to NERC over a secure connection using NERCnet **211** during data acquisition and validation **210**. The data may have been sent, for example, by one or more (up to all) of 123 Control Areas. The received data is archived (i.e., collected and concentrated) in one or more NERC database servers **216**. The data may also be processed using ACE and/or AIE applications. Output results go, for example, via XML, and SOAP technologies to a browser base clients.

The archived data may also be provided to NERC applications and web server **218**. The NERC applications and web server communicate with an early notification e-mail server **222** and/or Reliability Authorities web browser **220** over the Internet. For example, The NERC applications and web server may broadcast ACE-AIE key data to the Reliability Authorities every 60 seconds. The early notification e-mail server **222** may be used to notify abnormal events via e-mail **212**. The monitoring and tracking by 22 Reliability Authorities may include graphic and geographic displays using the performance monitoring technology platform of the power grid monitoring and management system of the present invention.

FIG. **16** is a screen shot **220** that illustrates a multiple view architecture of a display of the power grid monitoring and management system in an exemplary embodiment according to the present invention. The screen shot includes a real-time monitoring panel **222** used for graphical monitoring, a tracking panel **224** used for displaying tracking information, and a forecast panel **226** used for displaying prediction. The screen shot **220** also includes a text data/horizontal scroll panel **228** for viewing/scrolling text data.

In an exemplary embodiment according to the present invention, the CMS of the power grid monitoring and management system provides to Security Coordinators the tools to monitor each Control Area (CA) within their area of responsibility. Using the CMS, each Control Area will be reporting their ACE and AIE. For example, each of the Control Areas may report in one-minute intervals its ACE, frequency and AIE data through the NERCnet to the NERC Web Server. This data may be matched to the ACE/Frequency validation Matrix, the ACE-CMS database and presented back to each Security Coordinator utilizing the CMS. The compliance monitoring (reliability compliance) may also include CPS monitoring and inadvertent monitoring.

Therefore, the Security Coordinator will have the ability to view the CA performance using the graphic geographic visualization for Interconnections, Reliability Regions, Reliability Authority, Control Area and RTOs. Within these graphic displays the local hourly ACE may be presented in 2D and/or 3D. The power grid monitoring and management system also allows the user to display the ACE over different periods of time. These periods of time may range from the last scan to a thirty day history. The selection of all the Control Areas to an individual Control Area may be available to the user. In the described exemplary embodiment, there are three basic views for use in viewing these areas. An interactive replay of historical data may also be available. The replay element may, for example, allow for 24 hour, 48 hour, 7 day and 30-day replays.

The exemplary CMS presents the user with several different graphics. The Cave diagram is one of those graphic that is used as a tool to represent frequency/ACE, frequency/CPS1 and Epsilon1/calendar. The CPS1 pertains to a limit, which is a constant derived from a targeted frequency bound reviewed and set as necessary by the NERC Performance Subcommittee. Over a year, the average of the clock-minute averages of a Control Area's ACE divided by −10□ (□ is control area frequency bias) times the corresponding clock-minute averages of interconnection's frequency error must be less than this limit to comply with CPS1. To comply with CPS2, the average ACE for each of the six tem-minute periods during the hour (i.e., for the ten-minute periods ending at 10, 20, 30, 40, 50 and 60 minutes past the hour) must be within specific limits, referred to as L10. An Epsilon (□) is a constant derived from the targeted frequency found. It is the targeted root mean square (RMS) of one-minute average frequency error from a schedule based on frequency performance over a given year.

The Cave diagram **230** in FIG. **17** represents a Frequency/ACE diagram. Time is displayed on the horizontal axis. The upper graph vertical axis **232** displays the ACE. The lower graph vertical axis **234** displays the frequency. These two elements are used to develop the Cave graph. This type of graph is used as a tool for the review of current data as well as historical data in an exemplary embodiment according to the present invention.

The ACE function allows the user to view data for Epsilon1, ACE, and CPS1. Hence, the user is allowed to view the global, local or tracking data depending on what the user requires can disseminated the data further. The global function may be used to look at one or more of the Epsilon, the local ACE and tracking CPS1.

Referring back to FIG. **11**, the CMS receives data from the Control Areas (Data Collection **162**) and compares this received data to the submitted compliance data from each Control Area (Standards & Algorithms **166**). The results of these comparisons are then displayed graphically (Visualization **164**) on a geographical map (Geography **168**). The five tiers of display start with the ISO RTO, Control Areas Reliability Authority, Reliability Regions and Interconnections.

FIG. **18** is a screen shot **240** of a default display for a Reliability Authority in an exemplary embodiment according to the present invention. The boundary tabs that appear at the top left side of screen represent the reliability organizations entry points. The five boundary tabs that are used for the CMS in the described exemplary embodiment are as follows: 1) Interconnections; 2) Reliability/Regions; 3) Reliability Authority (default); 4) Control Area; and 5) ISO RTO.

The Interconnection Map is divided into the four (4) NERC Interconnections, West, East, Quebec and Texas. The Reli-

ability Region tab allows the user to view the map in a Region format. The Reliability Authority tab allows the user to view the 20 Reliability Authority areas of responsibility. Further, the Control Areas tab will give the user a map of all the NERC Control Areas. In addition, the ISO RTO map displays the thirteen (13) RTOs. In each of these maps, the Interconnections and/or other areas that do not submit data to the CMS are shown in black. In FIG. **18**, for example, Texas is shown in black as it is not currently submitting data to the CMS.

In each of the five boundaries, the current ACE and ACE/L10 data is displayed. The corresponding data is presented in a dynamic window **244** that appears at the bottom center of each map. As shown in FIG. **18**, the dynamic window has four tabs: 1) Overview; 2) Worst/Best CA's; 3) Reliability Authority Data, which changes to the boundary selected); and 4) Control Area (inner circle).

In the power grid monitoring and management system of the described exemplary embodiment, a 3D map may also be displayed. In addition, the network lines may be generated on the map. Further, the user may also be able to view global Epsilon for the Interconnections. Epsilon is a function of frequency. It is a constant derived yearly from the targeted Interconnection frequency deviations found from the prior year. This constant is used to compare the last hour frequency performance against this constant, and used to assist the CPS Regional Authority on knowing how the Interconnection control has performed. For example, when the constant and measured value equal a number between 0-8 the map may be colored in blue ("good") for that Interconnection. Should the comparison of the Epsilon be greater than 8, but less than 10 then that Interconnection may appear as green ("satisfactory") on the Interconnection map. Similarly, the Interconnection may appear yellow ("warning") between Epsilon of 10-11 and red ("violation") for Epsilon greater than 11.

The Epsilon for the selected one or more Interconnections for the past 24 hours may be viewed, for example. FIG. **19** is a screen shot **250** of an Interconnect-Epsilon map in a three-panel display in an exemplary embodiment according to the present invention. It can be seen in a first panel **251** that the United States is divided into four Interconnections: 1) Western (W) **252**; 2) Eastern (E) **253**; 3) ERCOT (T or Texas) **254**; and 4) Quebec (Q) **255**.

The user may select one or more Interconnections for view. In the screen shot **250**, the "Daily Interconnection Map—Last 24 Hours Epsilon" **251** occupies the first panel. The "Daily Image Panel" **256** is in the upper right hand corner, and the "Daily Plot Panel" **258** is located in the lower right hand corner of the display. To have any one of the panels viewed as a full screen for better viewing, the desired panel may be right clicked to bring up a pop-up menu. By selecting "Maximize", the Panel may be shown as a full screen. The power grid monitoring and management system also allows for replaying using a replay function, for example. The replay may be up to 24 hours or more, for example. The replay speed may also be controlled to be slower and/or faster.

FIG. **20** is a screen shot **260** of a local view for a Control Area map in an exemplary embodiment according to the present invention. The graphic in the view of FIG. **20** shows the ACE and ACE/L10. The Control Areas' ACE and/or ACE/L10 may be color coded so that as the Control Area's "ACE" changes the colors may be represented for the Control Area. For example, the ACE of −200 to −100 may be represented by red, −100 to 0 by yellow, 0 to 100 by green and 100 to 2000 by blue.

Also for the local view, a three-panel display may be displayed for a specific Control Area. The adjacent Control Areas may be defined as two Control Areas that are interconnected: 1) directly to each other; or 2) via a multi-party agreement (e.g., ISO and Power Pool agreements) or transmission tariff Selecting Adjacent 0 may show only the Control Area, Adjacent 1 may show adjacent Control Areas, and Adjacent 2 may go out to the second level out away from the selected Control Areas. Selecting All may select all Control Areas. An actual interchange is a metered interchange over a specific interconnection between two physically adjacent Control Areas. An inadvertent interchange is a difference between the Control Area's net actual interchange and a net scheduled interchange.

For example, FIG. **21** is a screen shot **270** of a current Control Area map for a selected Control Area **272** in an exemplary embodiment according to the present invention. The selected Control Area **272** is shown in yellow on the ACE map. The upper right hand corner shows a last hour ACE **274**. This display is broken into 10-minute increments. A Cave graph **276** displays frequency and ACE for the last hour. The last hour ACE and the hourly Cave may also be displayed separately in the full screen. Similar to the global view, the local view ACE may be replayed for last 24 hours or more, during which the replay speed may be adjusted to become faster and/or slower.

FIG. **22** is screen shot **280** of a CPS map in an exemplary embodiment according to the present invention. The CPS map in the described exemplary embodiment is the same for each of the five boundary tabs. The CPS map may be color coded to visually give the user, for example, a view of the number of items in the ten (10) minute window of CPS1 that the ACE did not cross zero for the last hour when compared to the Control Area's stated CPS1. For example, blue may represent 0 to −100%, green may represent 0 to 100%, yellow may represent 100% to 200%, and red may represent 200% to 1,000%.

By selecting the Control Area, and selecting a daily or monthly view, a three-panel view may be obtained for the Control Area and/or adjacent areas. For example, FIG. **23** is a screen shot **290** of a three-panel view in an exemplary embodiment according to the present invention. This particular map, for example, was generated using Adjacent 1 feature. From this screen, a replay of last 24 hours or more may be obtained. Further, the replay speed may also be controlled to be faster and/or slower.

FIG. **24** is a screen shot **300** of a data collection tool in an exemplary embodiment according to the present invention. The data collection tool may allow the user to view/extract raw data from the NERC database. This tool may be used to view the data that has been collected for the user to analyze. Using the collected data, one or more charts may be generated as shown on a screen shot **310** of FIG. **25**, for example.

FIG. **26** illustrates utilization of NERC ACE-frequency monitoring **315** in an exemplary embodiment according to the present invention. The power grid monitoring and management system receives an early abnormal notification **320**. Then a root cause assessment **322** is performed for Regions and Control Areas with ten (10) worst ACEs, for example. Of these Regions and Control Areas, the root cause is pinpointed (**324**). Further, the Interconnection Control Areas Frequency-ACE and Root Cause Control Area ACE-Frequency are analyzed (**326**, **328**).

FIG. **27** illustrates a screen shot **330** of a supplier-Control Area performance for AGC and frequency response application in an exemplary embodiment according to the present invention. For example, as can be seen in a first panel **332**, real-time monitoring can be performed by zones, resource types and/or by owner. Actions/results may be viewed through horizontal scrolling and/or tabular display **338**. Fur-

ther, a simulation or replay may also be performed/displayed. In the other panels **334** and **336** of the three-panel display, a historical performance tracking and delta forecast for the next six (6) ten minute periods, respectively, are also displayed.

FIG. **28** illustrates a market monitoring system **340** in the power grid monitoring and management system in an exemplary embodiment according to the present invention. In the market monitoring system **340**, a market monitoring center **342** (in the power grid monitoring and management system) receives systems conditions **344** such as market power, price spikes, demand forecast error, safe regulation bands and/or new control metrics. Also, the market monitoring center **342** receives market metrics such as blue alert, green alert, yellow alert and/or red alert. Then the market monitoring center performs actions **347** such as market performance metrics notification, remedial actions (e.g., re-dispatch), emergency actions and/or suspend rules. Further, the power grid management system monitors system conditions, track market metrics, assess predictive risk management, and the like (**348**).

FIG. **29** illustrates a screen shot **350** of a market monitoring application (of the power grid monitoring and management system) in an exemplary embodiment according to the present invention. For example, the system monitors (**352**) prices/spikes, imbalance energy, market power indices, and/or demand forecast error. Further, the system is used to take corrective actions (**354**) such as re-dispatch, price caps, suspend market rules and/or automatic mitigation. In two other panels of the three panel view of FIG. **29**, the system also tracks (**356**) historical performance by generator, control area, market and/or supplier, and/or the like, and bid sensitivities (**358**) for generator, portfolio and/or Control Area.

The power grid monitoring and management system in an exemplary embodiment according to the present invention performs Security Center monitoring. The Security Center operational hierarchy may include one or more of: 1) Security Monitoring Center using current and future synchronized data; 2) NERC 22 Reliability Coordinators; 3) RTOs/ISOs, Control Areas; 4) transmission only providers; 5) generation suppliers; and 6) load serving entry.

FIG. **30** illustrates a Security Center monitoring system (of the power monitoring and management system) in an exemplary embodiment according to the present invention. A Security Center **362** receives composite security indices **364**, which include synchronized data network, supply adequacy metric, voltage/VAR adequacy, congestion management and/or market dysfunction. The Security Center also receives security alerts **366**, which include red, orange, yellow, green and/or blue alerts. The Security Center **362** in coordination with a Security Coordinator **367** tracks composite security indices **368**, monitors composite security metrics **372**, assesses predictive risk management **374**, and coordinates with Reliability Coordinators level **370**. FIG. **31** illustrates a screen shot **380** of a real-time security monitoring application (of the power grid monitoring and management system) in an exemplary embodiment according to the present invention. The system performs a real-time monitoring of composite security indices (**382**), and also tracks the composite security indices (**388**). In addition, the system coordinates with NERC Reliability Coordinators. Further, the system also provides actions, phone numbers and e-mails to facilitate the coordination (**386**).

FIG. **32** is a block diagram of a NERC reliability functional model **390** in an exemplary embodiment according to the present invention. The power grid monitoring and management system in exemplary embodiments according to the present invention facilitates the integration process, focusing first on the applications required by the stakeholders within a dotted line **392**. Functions within the dotted line include reliability coordination **393** and compliance enforcement **394**, balance authority service acquisition **395**, load servicing entities procurement **396** and the actual usage of the services by the transmission operators **397**.

In an exemplary embodiment according to the present invention, the power grid monitoring and management system is adapted for the monitoring, tracking and short term prediction of CAISO CA and suppliers response to AGC, FRR, and ancillary services (A.S.) regulation performance/requirements. In the described exemplary embodiment, the power grid monitoring and management system will track and predict both the Control Area's and the supplier's performance for the above three services (AGC, FRR and A.S.). The power grid monitoring and management system, for example, may be used by the real-time operators, the operating engineering staff and/or management.

The real-time operators may obtain one or more of the following benefits through the present invention: 1) enhanced ability to monitor and track the CAISO Control Area and Suppliers response to AGC, including the ability to segregate into areas, (e.g., Northern and Southern California) and suppliers; 2) identify Control Area and supplier's actions, their performance and near real time predictions to frequency response; 3) identify and provide information for possible required changes in next hour's scheduled A.S. for Regulation; 4) identify and provide information for possible required changes in next day's scheduled A.S. for Regulation; and 5) one general overview display that show all three functions. More detailed displays may be available for each area.

The operating engineers may reap one or more of the following benefits from the power grid monitoring and management system of the present invention: 1) provides them with unit specific performance information; and 2) provides them with information that allows them to work with plant owners to improve their response to AGC, FRR and A.S. Regulation. Further, the power grid monitoring and management system of the present invention may provide to the management near real-time operational information that allows them to evaluate the effectiveness of market rules and tariffs.

The power grid monitoring and management system may also provide reliability services to the relationships between operational reliability objectives, services required for reliable operations and the roles and responsibilities for the control and operation authorities. For example, the reliability services may be provided to transmission reliability, supply resources and demand balance, and A.S. markets.

Returning now to FIG. **6**, the top half of FIG. **6** shows the architectural overview of the application of the power grid monitoring and management system for monitoring real-time control performance at the reliability coordinator level. The applications have been designed, deployed and tested for the NERC Reliability Coordinators. The bottom half of FIG. **6** shows the overview for the Control Area level. The power grid monitoring and management system integrates response to AGC, FRR and A.S. to effectively visualize how the CAISO Control Area and Suppliers are performing for each of the three areas.

A System operator normally has an available range of AGC control, both up and down, displayed on some type of general overview. These values, in today's systems, are normally mapped into these overviews as provided by successful bidders of Regulation A.S. This AGC range & ability governs many decisions made on real time (i.e., magnitude of Control Area Interchange ability, coverage of manually directing on-

line generators for various reasons, etc.). In one exemplary embodiment, the AGC module of the power grid monitoring and management system qualifies the accuracy and performance of that AGC range as it happens and records it. For example, the AGC module may display and track how much a generator on AGC control is signaled to move in MW and presents various displays/documentation on how well (or not) that requirement is/was being met.

The user may have the ability to see generator response to AGC in real-time. Aside from over-all aggregate views, the user can display (select or "turn on") a segregation of generators into zones (e.g., Northern California and Southern California) and suppliers, which could aid real-time decisions. As an example, monitoring could show all generators in the north meeting 100% response requirements and only 70% in the south, dictating possible manual intervention for an upcoming large ramp that might leave undesired loadings on constrained paths (e.g., Path **15**). Aside from regional segregation ability, the power grid monitoring and management system can also separate displays into types of generators (i.e., 150 Mw, 750 MW, Hydro, etc.).

The displays for tracking may show the response performance of suppliers to AGC for the previous hour, day and week. By utilizing historical response data, the application may predict the response performance of each supplier to AGC for the next 10, 20, 40 and 60 minutes.

In Summary, the AGC module may achieve/produce one or more of the following: 1) a visual representation of the real-time performance of each generator on AGC; 2) various options of displaying aggregate and detailed information on AGC units; 3) provisions for alarm points when established parameters are met; 4) selectable Time Period Displays and Printouts, (Previous Hour, Day, Week) of a generator's performance. They can be used for monetary penalties in billing and for various analysis efforts; and 5) can be used for near real time prediction. (10, 20, 40 and 60 minutes). The system overview visualizations to show the above functionalities will be discussed later.

In an exemplary embodiment according to the present invention, the power grid monitoring and management system provides control area and suppliers response performance monitoring, tracking and prediction to FRR. Historically, having NERC Standards in place has provided adequate assurance that the Control Areas and interconnected generators within each Interconnection, as well as load shedding, were able to effectively respond to contingencies and adequately arrest frequency excursions, thereby meeting design expectations. Within the WECC (i.e., Western Interconnection), the normal and expected change in system frequency for the loss of 1,000 MW of generation has been a 0.1 Hz decay. In recent years, however, it is not unusual to experience a 0.1 Hz decay in system frequency with only a 300 or 400 MW loss of generation. So FRR Monitoring, Performance Tracking and Prediction implementation at CAISO is desirable.

The following example illustrates a frequency decay by 0.2 Hz for a loss of about MW. It appears, for whatever reasons, that the overall frequency response of the interconnected system has changed significantly, in a negative way. The exemplary embodiment implements new standards, specifically addressing the issue of frequency response, and establishing the necessary monitoring and tracking system(s) to evaluate the performance of the frequency responsive resources and the Control Area.

A Control Area's frequency response performance is the result of how good or bad all the Frequency Response resources connected to the transmission system respond and perform. This application will monitor, track, and project Frequency Response Reserves performance in the CAISO Control Area.

Major functions of the FRR module may include one or more of:

1) Performance—monitor the performance of the CAISO's Control Area response to frequency excursions, calculate the MW/0.175 Hz deviation and determine if the Control Area is in compliance with the proposed NERC/WECC FRR standards. In addition, the application may monitor the actual performance of each of the frequency responsive resources that are expected to support the Control Area response to frequency excursions and calculate their contribution per MW/0.175 Hz deviation. This module will provide the answer to the question, "Which resources are contributing to the Control Area's overall compliance with the Frequency Response Reserves (FRR) standards?";

2) Tracking—time tagging and archiving of actual data associated with monitoring performance and MW/0.175 HZ deviation performance of the Control Area to frequency excursions, as well as the performance of the individual frequency responsive resources. Data may be stored in a time series database and used to present the pattern and behavior of specific resources. Historical data may also be used to feed the prediction module. It can also be an ingredient of any required disturbance control standard (DCS refers to the standard which requires the ACE to return either to zero or to its pre-disturbance level within 15 minutes following the start of the disturbance, which is a) any perturbation to the electric system, or b) an unexpected change in ACE that is caused by the sudden loss of generation or interruption of load.);

3) Probabilistic prediction—provide the CAISO staff with a prediction of the expected performance of the frequency response resources to the next frequency excursion. A more accurate forecast of the upcoming performance in meeting the FRR standards may allow the CAISO to maintain and improve system reliability and market efficiencies. If the prediction module of the application determines that the anticipated resource configuration is inadequate in meeting the FRR requirement, it can produce a suggested alternative or additional resource requirements; and

4) Visual Analysis—the power grid monitoring and management system visual analysis layer may facilitate the interpretation of the results from each of the major functions. Taking advantage of the visualization technology available in the power grid management system, it may present past, current and near term future information to the CAISO staff on tabular, graphical and/or geographical displays. The application may provide the ability to segregate suppliers into zones, such as Northern & Southern California, and also of the various "types" of generators.

Load shedding on non-critical loads is another FRR resource that the system operator may have to adjust frequency. For this reason, the performance of load shedding (measured as MW/0.175 Hz) as a frequency control resource may also be determined, tracked and predicted.

The suppliers response performance to AGC previously explained, displayed and recorded what each and all Control Area regulating generators were signaled to move and how they performed, relative to that signal. This application may track and record the delta or difference between what the supplier bid in regulation service for the Hour Ahead Market and its actual response.

Ancillary Service of regulation is normally prescheduled for the hour ahead (and day ahead) via the marketplace. A successful supplier of regulation will normally have an up and down magnitude, although one direction only can occur. In

conjunction with that MW range, a ramping (rate of change) magnitude is also provided by the supplier, normally in percentage or MW/minute.

The displays for monitoring of this application will show and record how well a generator is providing regulation, follows control signals sent by CAISO's Energy Management System Computer and will compare it to the parameters (ramp rate) provided by the supplier (Bid, Contract or Plant Information) in the Hour Ahead or Day Ahead Market.

The displays for tracking will show the supplier's historical response performance to the hourly ancillary services market for the last day and week. This information could be shared with the suppliers that provide this service, to improve quality, or even be made inclusive of the payment structure when stipulated non-performance occurs.

The displays for prediction will show the suppliers predictive response performance to hourly ancillary services one, two, three and/or four hours ahead. For example, suppose next hour's Regulation range is displaying a 500 MW upward quantity, with a 25 MW/Min aggregate ramp rate, provided by the marketplace. Utilizing historical performance data, this application will note what sources are providing this regulation range and "quantify" it for the System operator. It could, for example, note that only x-amount is available over a designated time period or that only 15 MW/Min rate of change is achievable. If that reality is unacceptable, the system operator may have the option of utilizing other hourly or 10 minute sources to mitigate adverse balancing and reliability effects. This will apply to either increasing or decreasing load requirements.

A System operator will often have a need to appraise what resources have been planned for some near short term future hours. This can be the result of unplanned outages of generators, internal transmission lines, interconnection transmission lines and other events. This application gives a little longer look than the Hour Ahead program in respect to Ancillary Services Regulation.

Similar to the Hour Ahead function, the monitoring associated with this module is focused on those regulation ancillary services that were attained from the Day Ahead Market only and will display relative comparisons of actual performance vs. market bids in these regulation services.

Historical performance data for the past day and week will be available in the displays of this module. This data could be used in conjunction with the Hour Ahead Performance by comparing records for various validations or determinations between the two markets. They can also be shared with the suppliers for improved quality of service or included in the payment structure for performance penalties. The power grid management system may also allow the user, using historical performance data, to predict the performance of the day ahead committed resources of ancillary services for regulation by choosing the display option of Day Ahead Market.

Based on NERC current reliability guides, drafts standards for NERC and WECC Frequency Response Reserves (FRR) and input from the CAISO's system operators and management, the key functional capabilities for the power grid monitoring and management system for CAISO may include one or more of: 1) performance monitoring of CAISO's CA and suppliers to AGC; 2) performance monitoring of CAISO's CA and suppliers to FRR; and 3) performance monitoring for CAISO's CA and suppliers to Hourly and Day-Ahead Ancillary Service Regulation.

The Control Area's frequency response performance is the result of how good or bad all the frequency responsive resources connected to its transmission system perform. The challenge for the Control Area is how to determine the actual performance of each resource vs. expectations.

Although this application has the ability and will evaluate the Control Area performance to determine compliance with the FRR Standards, the primary focus of the application is to monitor and track the actual performance of the individual frequency responsive resources connected to the grid. As stated above, it is the performance of each and every resource connected to the CAISO's grid that will determine the Control Area's overall frequency regulation performance.

The purpose of the proposed application is to provide sufficient and meaningful information for the CAISO management and staff to: 1) maintain system reliability and ensure compliance with NERC and WECC reliability standards, by monitoring in real time the response performance of CAISO's CA and suppliers to the AGC, FRR and A.S.; and 2) improve the efficiency of the A.S. market. The Table 1 below, for example, shows functionalities in an exemplary embodiment according to the present application.

TABLE 1

Overview of Functionalities

	Service		
Function	CA&Suppliers Response to AGC	CA&Suppliers Response to FRR	CA&Suppliers Response to A.S.
Monitoring	Scheduled vs actual response in last one-minute interval Performance Indices	Expected vs actual response in last frequency excursion Performance Index	Last Bid vs actual response Performance Index
Tracking	Previous hour, day and week scheduled vs actual response Historical Performance Index	History of Deviations (MW/0.175 Hz) performance to frequency excursions of CA and suppliers Historical Performance Index	Last day supplier response to A.S. markets Last week supplier response to A.S. markets Historical Performance Index
Predictions and Probability bands	10 Minutes Ahead 20 Minutes Ahead 40 Minutes Ahead 1 hour ahead Probability bands Bad data identification and replacement	Next frequency excursion, twenty and sixty seconds response Probability bands Bad data identification and replacement	1, 2, 3 and 4 hours ahead for hour market Day ahead market Probability bands Bad data identification and replacement

It should be noted that the tracking function may serve as a simulation tool.

In monitoring the response performance to AGC of CAISO CA and suppliers, the system operator may first look at the display of the one-minute supplier control error for each resource. A pie graph may be presented for each resource that is being monitored. Part of the pie indicates the expected response, other part the actual response and the last part the difference between the actual and the expected response. The pie will be color coded to indicate the performance of the generator response for the last one-minute period. The cylinder height, also color-coded, represents the performance index. The performance indices are defined herein later on.

For the tracking of the response performance to AGC of CAISO CA and suppliers, the system operator has a chart

available with the historical values for the period that he/she specifies. The response prediction may also be offered to the System operator, for the next 10, 20, 40 and/or 60 minutes.

The system operator may then use these three pieces of information to decide how much to rely on each resource for AGC. For example, suppose actual part of the pie is red and the cylinder height is red. This means that the supplier is performing poorly recently. Analysis of the historical performance (tracking function) provides additional information to decide how reliable the supplier is. If the historical performance is poor, the forecast will also be poor. The System operator will integrate all this information to decide on a course of action for the resource under consideration.

Similar functionality will be offered for monitoring, tracking and predicting the response performance of CAISO CA and suppliers to FRR. Instead of one-minute values as in the resource response to AGC, however, the resource response to the historical average to frequency excursions may be displayed. Each supplier may be represented by two color-coded pies and a cylinder. The pie indicates the generator FRR actual response to the last frequency excursion and its expected response. The height of the cylinder may, for example, represent the performance index of the generator.

The functionality offered for monitoring, tracking and predicting the response performance to A.S. markets (hourly and daily) may, once again, be similar to the one of the previous two applications. Each supplier is represented by two color-coded pies and a cylinder. The pie represents the most recent response for the day ahead and hour ahead bids and the bids made by the suppliers in the A.S. markets. The cylinder height represents, as before, the performance index.

FIG. **33** illustrates a geographic-graphic visualization overview **440** of a control area and suppliers performance monitoring and prediction platform for AGC, FRR and regulation A.S. in an exemplary embodiment according to the present invention. As shown in FIG. **33**, the CAISO System operator will have available displays to monitor for the current time, last 24-hours and last X-minutes (default 10-minutes) both their CA and the individual suppliers response performance, forecast and tracking performance of CAISO AGC, Frequency Response Reserves (FRR), and hourly and daily Regulation Ancillary Services markets. In addition, besides having CA and suppliers performances for each service, CAISO System operators will also have available an integrated window that will show continuously the CA and suppliers performance for all four services simultaneously, and replay capability for displays on either of the panels from the 3-panel displays.

This application of the power grid management system allows the CAISO System operators and management to identify via 3-panel displays the CA and suppliers performance for each service on geographical displays for current time, the last ten minutes on co-plot displays, and for the past 24-hours on image-displays and user selected suppliers predictive performance. The bottom of the 3-panel displays will be user selectable, to switch from tabular text window correlated with the data in the 3 panels, to optionally show to System operators in a continuous horizontally scrollable window, the performance indices for AGC, FRR and regulation ancillary services. The indices will replay continuously for a selectable period of time that will include the prediction period.

FIG. **34** is a screen shot **450** of a panel view for control area and suppliers performance for, AGC, FRR and A.S. in an exemplary embodiment according to the present invention. It can be seen in FIG. **34** that there are five tabs at the top-left corner. Each of them presents a 3-panel display with the main panel, showing in a 3D map, the selected suppliers performance for the service selected and the other two panels showing the selected suppliers performance for the other two services. The three tabs at the top-right present the window for username/password, interface for user enterable parameters, and the help displays. The help displays, for example, may be based on Microsoft® PowerPoint® presentations.

The map and the cylinder pie-charts in the main panel display from the 3-panel display in FIG. **34** shows the current response of each supplier, selected from categorical options from a RMB menu, to the service selected from the tab. The other two panels also show the performance of the selected generators for the other two services.

The center-bottom of the 3-panel displays is user selectable to switch from tabular text window correlated with the data in the 3 panels, to optionally show to System operators continuously in a horizontally scrollable window the performance indices for AGC, FRR and regulation ancillary services. The indices will replay continuously for a selectable period of time that includes the prediction period. The three windows at the left-bottom of the screen contain the date/time for the data being displayed, an option to hold the automatic data refresh, and a yellow window to indicate the current action taken by the user

FIG. **35** is a screen shot **460** of a panel view for control area and generator response to AGC in an exemplary embodiment according to the present invention. FIG. **35** shows the 3D map and cylindrical pie-charts in the main panel display from the 3-panel display representing the current response of each generator, selected from categorical options from an RMB menu, to AGC, with the cylinder-height representing each generator performance index. The color of the CAISO control area may represent the response to AGC of all the suppliers providing the control area, represented by the performance indices previously discussed herein.

The image on the top-right panel shows the performance tracking of each of the suppliers online, selected from the RMB option, and may be color coded for the last 24-hours. The plot on the bottom-right panel shows the predictive plot. This plot includes a multi-series, time-based, linear chart. One series represents the recorded values of a variable over time and the second represents the predicted value for the same variable over the time period and for X additional predicted values. The plot also includes a vertical reference-line indicating the current time, relative to the time period being displayed. Multiple instances of this plot are used in the display, as illustrated, and the user selects the values for display via an options dialog.

The center-bottom of the 3-panel displays will be user selectable to switch from tabular text window correlated with the data in the 3 panels, to optionally show to system operators continuously in a horizontally scrollable window the performance indices for AGC, FRR and regulation ancillary services. The indices will replay continuously for a selectable period of time and will include the prediction period.

The three windows at the left-bottom of the screen contain the date/time for the data being displayed, an option to hold the automatic data refresh, and a yellow-window to indicate the current action taken by the user.

The two main windows at the right-bottom of the screen contain the navigation buttons that must be implemented as shown, and the replay bottoms that also must be implemented as shown.

The three tabs at the top-right present the window for username/password, windows for user enterable parameters, and the help displays based on Microsoft® PowerPoint® presentations.

FIG. **36** is a screen shot **470** for a panel view for control area and generators response to frequency response in an exemplary embodiment according to the present invention. FIG. **39** above shows the CAISO geographic map and color coded cylindrical pies placed at the geographic location of each selected generator, with part of the pie representing the generator latest FRR response, the other part its expected FRR value and the last part the difference between actual and expected response. The height of the cylinder represents the FRR performance index for each selected generator.

The plot on the top-right panel shows the FRR performance tracking of each of the generators online, selected from the RMB option during the most recent frequency disturbances. The plot on the bottom-right shows the current selected generators FRR performance together with its performance variance for the hour, and the value predicted for the next excursion.

FIG. **37** is a screen shot **480** for a panel view for control area and generators response to regulation A.S. in an exemplary embodiment according to the present invention. FIG. **40** shows the CAISO geographic map and two concentric circles located at the geographic location of each selected generator, with the inner most circle representing the generator actual response for both the day-ahead and hour-ahead bids, and the outer most circle representing its Ancillary Service (both day-ahead and hourly-ahead) scheduled values. The height of the cylinder represents the Ancillary Services (day-ahead and hour ahead) performance indices for each selected generator.

The image on the top-right panel shows the Supplier Control Performance System (SCPS) for each of the generators selected, color-coded for the last X-Minutes (default 10-minutes). The plot on the bottom-right panel shows the predictive plot. This plot consists of a multi-series, time-based, linear chart. One series represents the recorded values of a variable over time and the second represents the predicted value for the same variable over the time period and for X additional predicted values. The plot also includes a vertical reference-line indicating the current time, relative to the time period being displayed. Multiple instances of this plot are used in the display, as illustrated, and the user selects the values for display via an options dialog.

FIG. **38** is a screen shot **490** of a common view for performance of AGC, FRR and X-Minutes Ancillary Services Regulation (Default 10-Minutes) in an exemplary embodiment according to the present invention. The format of FIG. **38** is equivalent for all three services using the corresponding performance data and indices. The main-panel shows the condition plot. It is similar to a scatter plot, created using the variables of one of the three services, the parameters of one of the three services and the names of the selected generators for a configurable, 10 minute time period (at 1 minute sampling frequency).

The following describes how the chart should be created as shown in FIG. **38** in an exemplary embodiment according to the present invention:

1) Run the appropriate database stored procedure.

2) Determine from the user interface the value to perform grouping, by performance, parameter or time.

3) Determine the unique grouping values.

4) Determine the median parameter value for each generator (using the whole dataset) and order the generator list by that value.

5) Create a scatter plot for each unique grouping value, with the data value plotted on the X-axis. Each scatter point is colored according to a color map defined in a configuration file (Red/Yellow/Green).

6) The scatter plots will be arranged on a grid by increasing value, left to right, top to bottom.

The image on the top-right panel shows the performance index for each generator selected, color-coded for the last X-Minutes (default 10-minutes). The cave-plot at the bottom-right shows at the top the response MW of any generator selected from the image-plot, and at the bottom the scheduled MW for the selected generator.

It will be appreciated by those of ordinary skill in the art that the invention can be embodied in other specific forms without departing from the spirit or essential character thereof. The present invention is therefore considered in all respects to be illustrative and not restrictive. The scope of the present invention is indicated by the appended claims, and all changes that come within the meaning and range of equivalents thereof are intended to be embraced therein.

What is claimed is:

1. A wide-area real-time performance monitoring system for monitoring events on an interconnected electric power grid in real time over a wide area and automatically analyzing the events on the interconnected electric power grid, the system comprising:

a monitor computer including an interface for receiving a plurality of data streams, each of the data streams comprising sub-second, time stamped synchronized phasor measurements wherein the measurements in each stream are collected in real time at geographically distinct points over the wide area of the interconnected electric power grid, the wide area comprising at least two elements from among control areas, transmission companies, utilities, regional reliability coordinators, and reliability jurisdictions;

a plurality of interfaces to other power system data sources, the other power system data sources comprising at least one of transmission maps, power plant locations, EMS/SCADA systems; and

a plurality of interfaces to non-grid data sources,

wherein the monitor computer is configured to monitor metrics, the metrics comprising at least one of reliability metrics, power grid operations metrics, generation metrics, transmission metrics, suppliers metrics, grid infrastructure security metrics, and market metrics over the wide area of the interconnected electric power grid,

wherein the monitor computer is configured to detect the events in real-time from the plurality of data streams from the wide area,

wherein the monitor computer is configured to execute event detection logic, the event detection logic being configured to detect and analyze an event based on at least one of limits, sensitivities and rates of change for one or more measurements from the data streams and dynamic stability metrics derived from analysis of the measurements from the data streams including at least one of frequency instability, voltages, power flows, phase angles, damping, and oscillation modes, derived from the phasor measurements and the other power system data sources in which the metrics are indicative of events, grid stress, and/or grid instability, over the wide area,

wherein the monitor computer is configured to automatically present event analysis results and diagnoses of events via a graphical user interface coupled to the monitor computer for concurrently displaying the event analysis results and diagnoses of events and associated metrics from different categories of data and the derived metrics in visuals, tables, charts, or combinations thereof,

wherein the data comprises at least one of monitoring data, tracking data, historical data, prediction data, and summary data,

wherein the graphical user interface is configured to display concurrent visualization of the measurements from the data streams and the dynamic stability metrics directed to the wide area of the interconnected electric power grid,

wherein the monitor computer is configured to accumulate and to update the measurements from the data streams, the dynamic stability metrics, grid data, and non-grid data in real time as to wide area and local area portions of the interconnected electric power grid, and

wherein the monitor computer is configured to derive a composite indicator of reliability that is an indicator of power grid vulnerability and is derived from a combination of one or more real time measurements or computations of measurements from the data streams and the dynamic stability metrics covering the wide area as well as non-power grid data received from the non-grid data source.

2. The performance monitoring system of claim **1**, wherein the monitor computer is configured to analyze the measurements from the data streams and the dynamic stability metrics and the graphical user interface is configured to display the results of analyzing the measurements from the data streams and the dynamic stability metrics.

3. The performance monitoring system of claim **2**, wherein the monitor computer is configured to determine whether an event took place by automated analysis of whether one or more limits, sensitivities, and rates of change of one or more of the measurements from the data streams and the dynamic stability metrics crosses a threshold and, when the at least one of the monitored metrics crosses the threshold in a local area portion of the wide area or across the wide area of the interconnected electric power grid, to identify at least one of a control area, a transmission company, a utility, a regional reliability coordinator or a reliability jurisdiction responsible for the local and/or wide portion of the interconnected electric power grid in which the threshold is crossed.

4. The performance monitoring system of claim **1**, wherein the monitor computer is coupled to a global computer network for receiving the plurality of data streams from the wide area and wherein the performance monitoring system can store data associated with the event and replay it for power grid system performance assessment, event diagnostics, root cause analysis of events and situational assessment of dynamic stability of the interconnected electric power grid in real time.

5. The performance monitoring system of claim **1**, wherein the wide area comprises a geographic area comprising one or more cities, counties, states or countries.

6. The performance monitoring system of claim **1**, wherein the monitor computer is configured to enable a user to drill down and visualize the metrics displayed on the graphical user interface at various geographical resolutions ranging from wide-area to local-area.

7. The performance monitoring system of claim **1**, wherein the monitor computer activates an alarm when an event is detected in at least one metric of the monitored metrics or combinations thereof.

8. The performance monitoring system of claim **1**, wherein the monitor computer is configured to generate a notification when an event is detected.

9. A wide-area real-time performance monitoring system for collecting, storing and analyzing event data and analysis of events on an interconnected electric power grid in real time over a wide area and automatically analyzing the events on the interconnected electric power grid, the system comprising:

a monitor computer including an interface for receiving a plurality of data streams, each of data streams comprising sub-second, time stamped synchronized phasor measurements wherein the measurements in each stream are collected in real time at geographically distinct points over the wide area of the interconnected electric power grid, the wide area comprising at least two elements from among control areas, transmission companies, utilities, regional reliability coordinators, and reliability jurisdictions;

a plurality of interfaces to other power system data sources, the other power system data sources comprising at least one of transmission maps, power plant locations, EMS/SCADA systems;

a plurality of interfaces to non-grid data sources;

a database configured to store the phasor measurements and a plurality of derived metrics; and

a display coupled to the monitor computer and the database for visualization of information relating to the plurality of the phasor measurements and the derived metrics relevant to assessing the real-time dynamic stability of wide area and local area portions of the interconnected electric power grid,

wherein the monitor computer is configured to monitor metrics, the metrics comprising at least one of reliability metrics, power grid operations metrics, generation metrics, transmission metrics, suppliers metrics, grid infrastructure security metrics, and market metrics over the wide area of the interconnected electric power grid,

wherein the monitor computer is configured to detect events in real-time from the plurality of data streams from the wide area,

wherein the monitor computer is configured to execute event detection logic, the event detection logic being configured to detect and analyze an event based on at least one of limits, sensitivities, and rates of change for one or more measurements from the data streams and dynamic stability metrics derived from analysis of the measurements from the data streams including at least one of frequency instability, voltages, power flows, phase angles, damping, and oscillation modes, derived from the phasor measurements and the other power system data sources in which the metrics are indicative of events, grid stress and/or grid instability, over the wide area, and

wherein the metrics associated with a detected event comprise include at least one of time of event, location of event, type of event, magnitude of event, and one or more key event related metrics such as frequency, delta frequency, voltage drop, reactive reserve margin, power transfer angle, voltage/volt-ampere reactive (VAR), frequency response, sensitivities and/or combinations thereof.

10. The wide-area real-time performance monitoring system of claim **9**, wherein the database is further configured to store the metrics associated with the detected event and to allow a user to query the database for event data by type, location, and history.

11. The wide-area real-time performance monitoring system of claim **9**, wherein the database is further configured to store the phasor measurements and the plurality of derived metrics in real time.

12. A method of detecting events on an interconnected electric power grid in real time over a wide area and auto-

matically analyzing the events on the interconnected electric power grid, the method comprising:

receiving a plurality of data streams, each of the data streams comprising sub-second, time stamped synchronized phasor measurements wherein the measurements in each stream are collected in real time at geographically distinct points over the wide area of the interconnected electric power grid, the wide area comprising at least two elements from among control areas, transmission companies, utilities, regional reliability coordinators, and reliability jurisdictions;

receiving data from other power system data sources, the other power system data sources comprising at least one of transmission maps, power plant locations, EMS/SCADA systems;

receiving data from a plurality of non-grid data sources;

detecting and analyzing events in real-time from the plurality of data streams from the wide area based on at least one of limits, sensitivities and rates of change for one or more measurements from the data streams and dynamic stability metrics derived from analysis of the measurements from the data streams including at least one of frequency instability, voltages, power flows, phase angles, damping, and oscillation modes, derived from the phasor measurements and the other power system data sources in which the metrics are indicative of events, grid stress, and/or grid instability, over the wide area;

displaying the event analysis results and diagnoses of events and associated ones of the metrics from different categories of data and the derived metrics in visuals, tables, charts, or combinations thereof, the data comprising at least one of monitoring data, tracking data, historical data, prediction data, and summary data;

displaying concurrent visualization of measurements from the data streams and the dynamic stability metrics directed to the wide area of the interconnected electric power grid;

accumulating and updating the measurements from the data streams and the dynamic stability metrics, grid data, and non-grid data in real time as to wide area and local area portions of the interconnected electric power grid; and

deriving a composite indicator of reliability that is an indicator of power grid vulnerability and is derived from a combination of one or more real time measurements or computations of measurements from the data streams and the dynamic stability metrics covering the wide area as well as non-power grid data received from the non-grid data source.

13. The method of claim **12**, further comprising:

analyzing the measurements from the data streams and the dynamic stability metrics; and

displaying the results of analyzing the measurements from the data streams and the dynamic stability metrics.

14. The method of claim **13**, further comprising:

determining whether an event took place by automated analysis of whether one or more limits, sensitivities, and rates of change of one or more of the measurements from the data streams and the dynamic stability metrics crosses a threshold; and

when the at least one of the measurements from the data streams and the dynamic stability metrics crosses the threshold in a local area portion of the wide area or across the wide area of the interconnected electric power grid, identifying at least one of a control area, a transmission company, a utility, a regional reliability coordinator, or a reliability jurisdiction responsible for the local and/or wide portion of the interconnected electric power grid in which the threshold is crossed.

15. The method of claim **12**, further comprising:

receiving data from the wide area over a global computer network and

storing and replaying event data for power grid system performance assessment, event diagnostics, root cause analysis of events and situational assessment of dynamic stability of the interconnected electric power grid in real time.

16. The method of claim **12**, wherein the wide area comprises a geographic area comprising one or more cities, counties, states or countries.

17. The method of claim **12**, further comprising enabling a user to drill down and visualize the metrics displayed on a graphical user interface at various geographical resolutions ranging from wide-area to local-area.

18. The method of claim **12**, further comprising activating an alarm when an event is detected in at least one metric of the measurements from the data streams and the dynamic stability metrics or combinations thereof.

19. The method of claim **12**, further comprising generating a notification when an event is detected.

20. The method of claim **12**, further comprising storing phasor measurements and a plurality of derived metrics in a database.

21. The method of claim **20**, further comprising storing in the database the metrics associated with a detected event and allowing a user to query the database for event data by type, location, and history.

22. The method of claim **20**, further comprising storing in the database the phasor measurements and the plurality of derived metrics in real time.

* * * * *

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(12) **United States Patent**
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(45) **Date of Patent: Jun. 19, 2007**

(54) **REAL-TIME PERFORMANCE MONITORING AND MANAGEMENT SYSTEM**

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G06F 15/173 (2006.01)

(52) **U.S. Cl.** **700/291**; 709/224

(58) **Field of Classification Search** 709/217–219, 709/223–225, 249; 700/83, 286, 291, 297; 702/60–62, 179–185; 703/18; 715/965, 715/969

See application file for complete search history.

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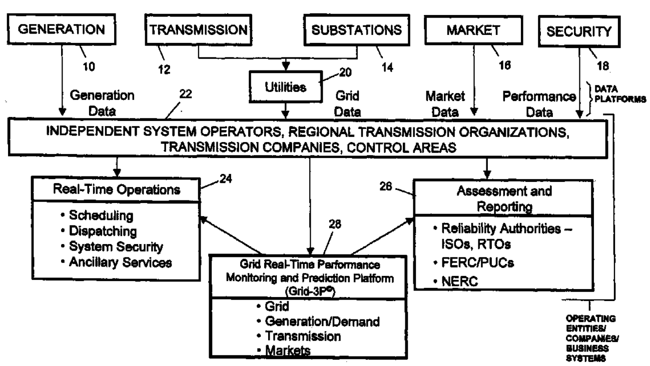
(57) **ABSTRACT**

A real-time performance monitoring system for monitoring an electric power grid. The electric power grid has a plurality of grid portions, each grid portion corresponding to one of a plurality of control areas. The real-time performance monitoring system includes a monitor computer for monitoring at least one of reliability metrics, generation metrics, transmission metrics, suppliers metrics, grid infrastructure security metrics, and markets metrics for the electric power grid. The data for metrics being monitored by the monitor computer are stored in a data base, and a visualization of the metrics is displayed on at least one display computer having a monitor. The at least one display computer in one said control area enables an operator to monitor the grid portion corresponding to a different said control area.

24 Claims, 41 Drawing Sheets



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Douglas A. Wiegmann, et al., "Human Factors Aspects of Power System Voltage Visualizations," Proceedings of the 35th Hawaii International Conference on System Sciences—2002, 6 pages.

AVS Advanced Visual Systems; www.avs.com/overview.html, 2 pages, 2004.

C. H. Wells, et al., "Real time Grid Stability Calculations at Entergy," pp. 1-7, no date.

Ioni Fernando, et al., "Real Time Online Evaluation of Small Signal System Damping Applied to Power System Stabilizer Commissioning and Testing," International Conference on Power Systems Transients—IPST 2003 in New Orleans, USA, pp. 1-6.

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Psymetrix Limited, "Power System Security Management—Technical Briefing," 2 pages, 2003.

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ABB Switzerland, Edition Feb. 2004, 34 pages.

Brian Johnson, "PCT International Search Report," Aug. 4, 2005.

* cited by examiner

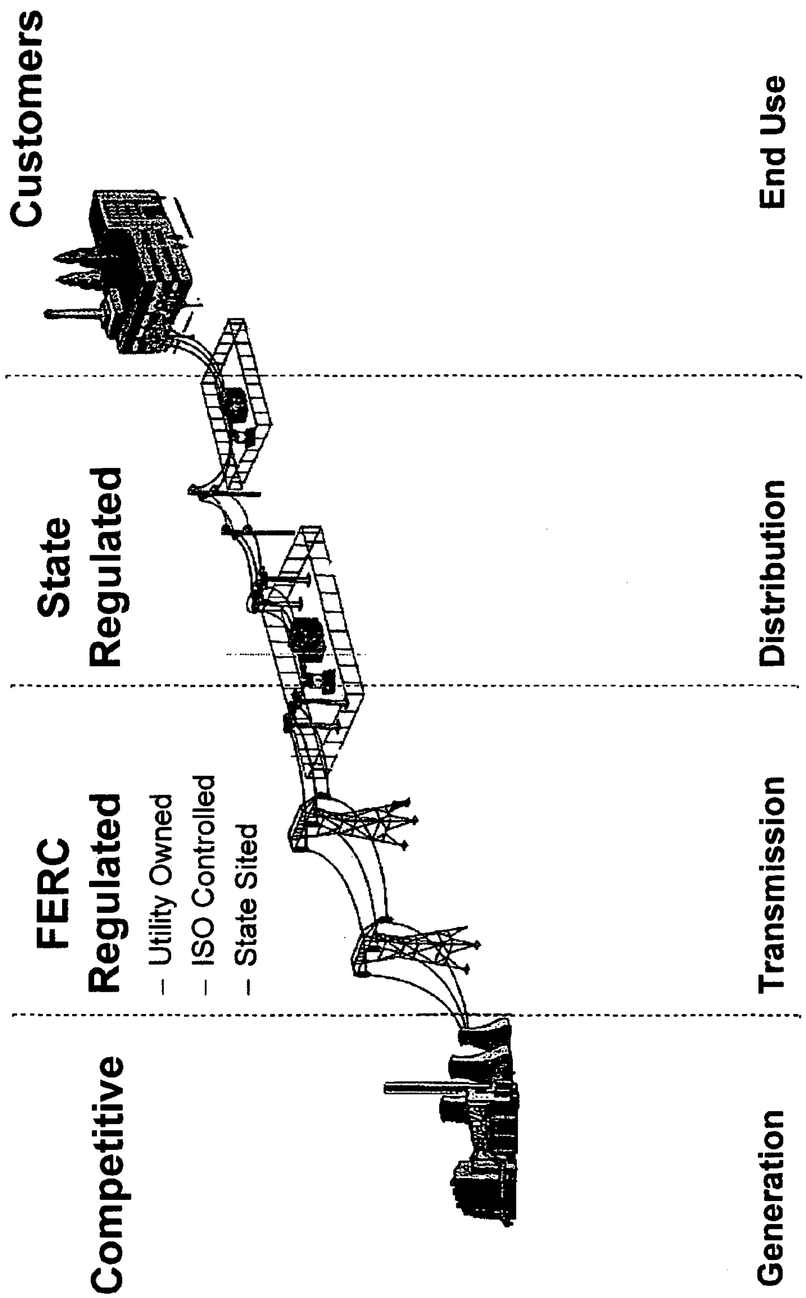


FIG. 1A
PRIOR ART

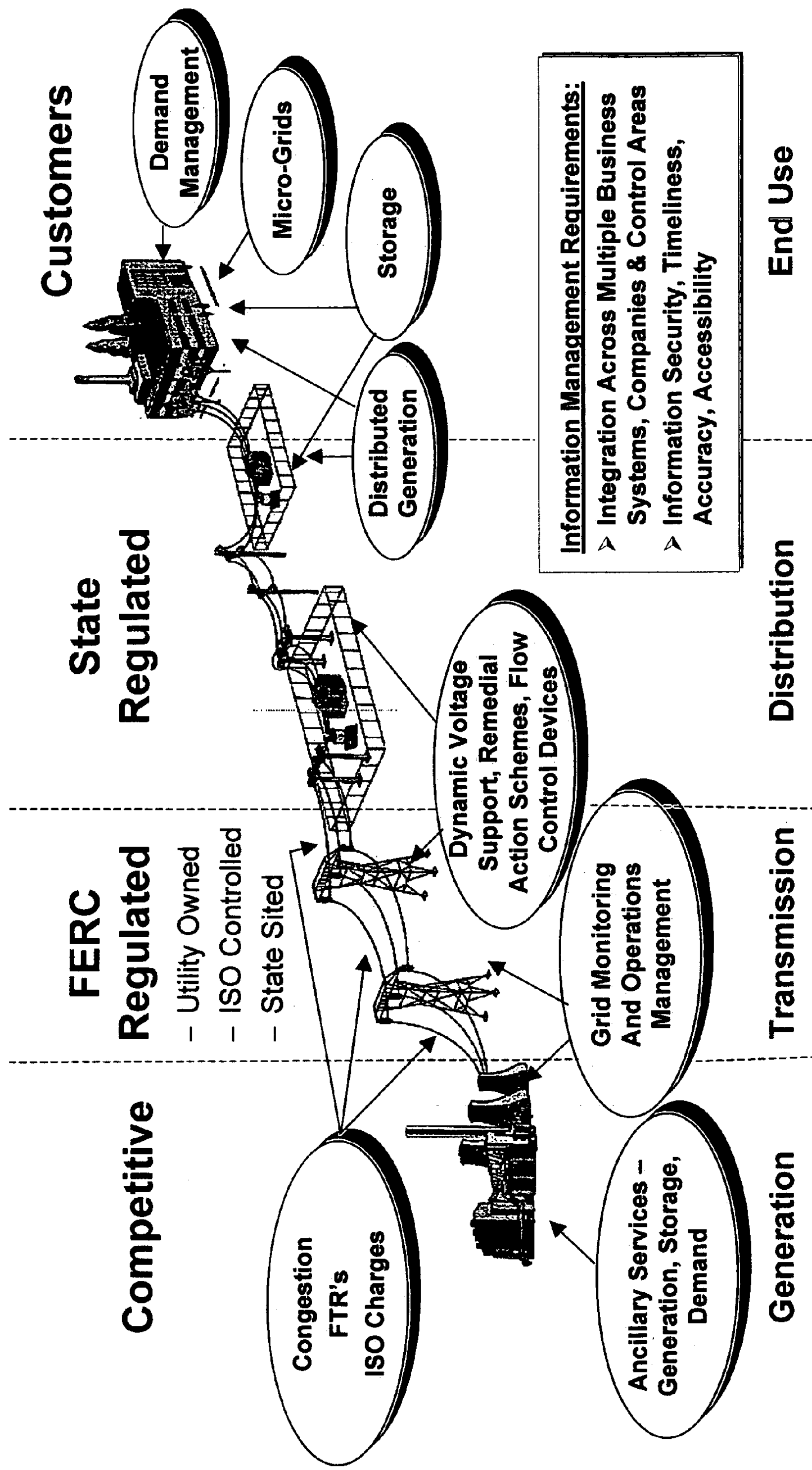

Competitive
FERC Regulated
– Utility Owned
– ISO Controlled
– State Sited
State Regulated
Customers
Congestion
FTR's
ISO Charges
Ancillary Services – Generation, Storage, Demand
Grid Monitoring And Operations Management
Dynamic Voltage Support, Remedial Action Schemes, Flow Control Devices
Distributed Generation
Storage
Micro-Grids
Demand Management
Information Management Requirements:
Integration Across Multiple Business Systems, Companies & Control Areas
Information Security, Timeliness, Accuracy, Accessibility
Generation
Transmission
Distribution
End Use

FIG. 1B

Performance Management Strategy

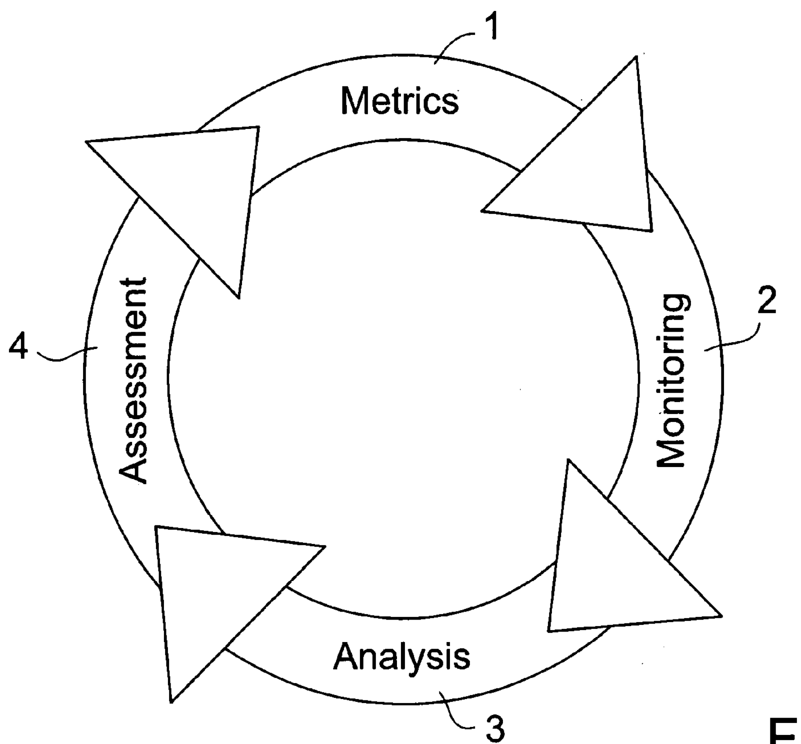


FIG. 2A

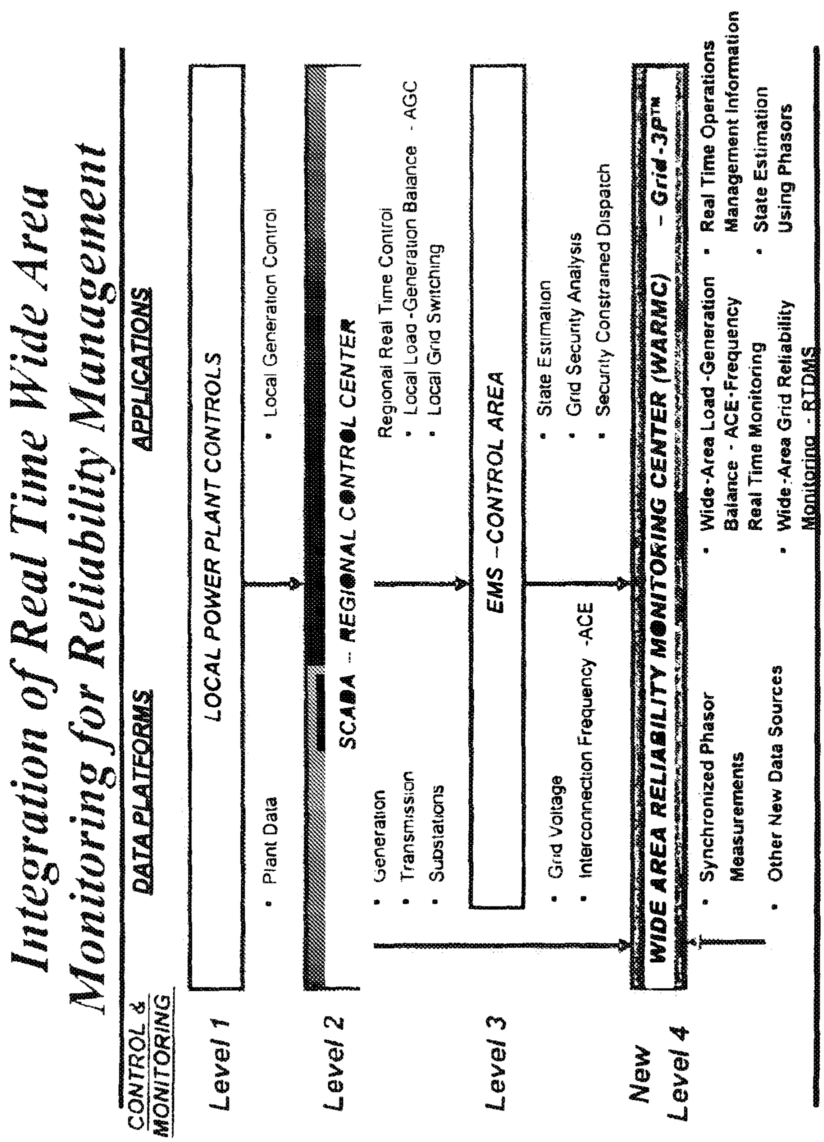

Integration of Real Time Wide Area Monitoring for Reliability Management
CONTROL & MONITORING
DATA PLATFORMS
APPLICATIONS
Level 1
LOCAL POWER PLANT CONTROLS
• Plant Data
• Local Generation Control
Level 2
SCADA – REGIONAL CONTROL CENTER
• Generation
• Transmission
• Substations
Regional Real Time Control
• Local Load -Generation Balance - AGC
• Local Grid Switching
Level 3
EMS – CONTROL AREA
• Grid Voltage
• Interconnection Frequency -ACE
• State Estimation
• Grid Security Analysis
• Security Constrained Dispatch
New Level 4
WIDE AREA RELIABILITY MONITORING CENTER (WARMC) – Grid-3P™
• Synchronized Phasor Measurements
• Other New Data Sources
• Wide-Area Load-Generation Balance - ACE-Frequency Real Time Monitoring
• Wide-Area Grid Reliability Monitoring - RTDMS
• Real Time Operations Management Information
• State Estimation Using Phasors

FIG. 2B

WARMC Infrastructure

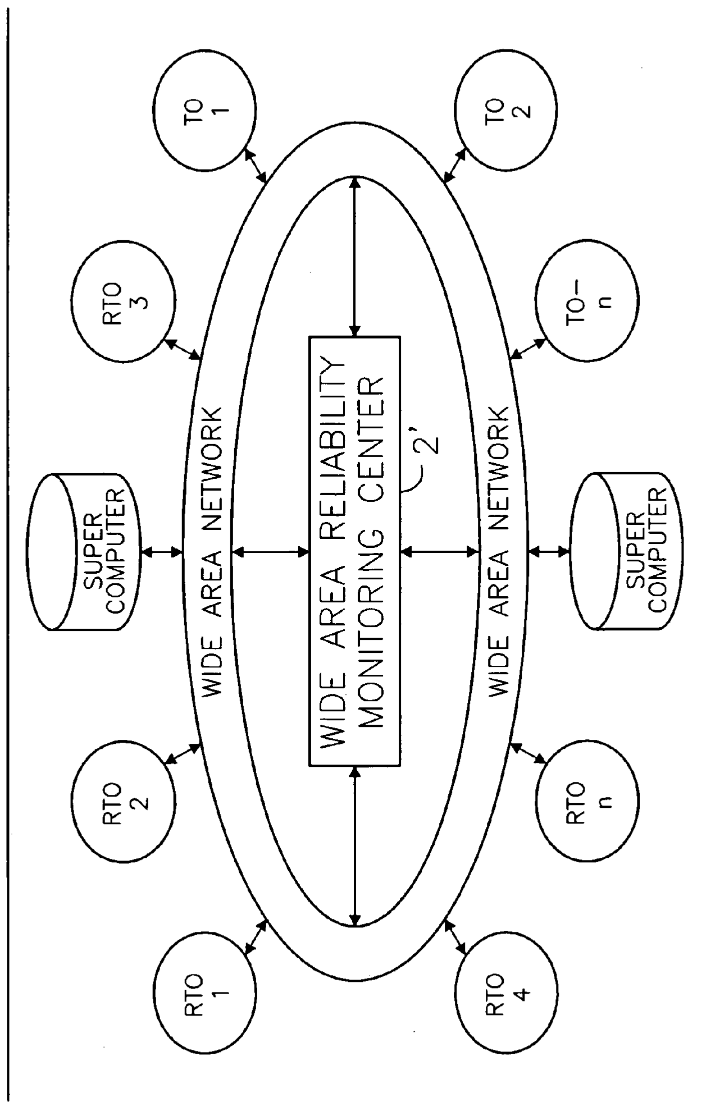


FIG. 2C

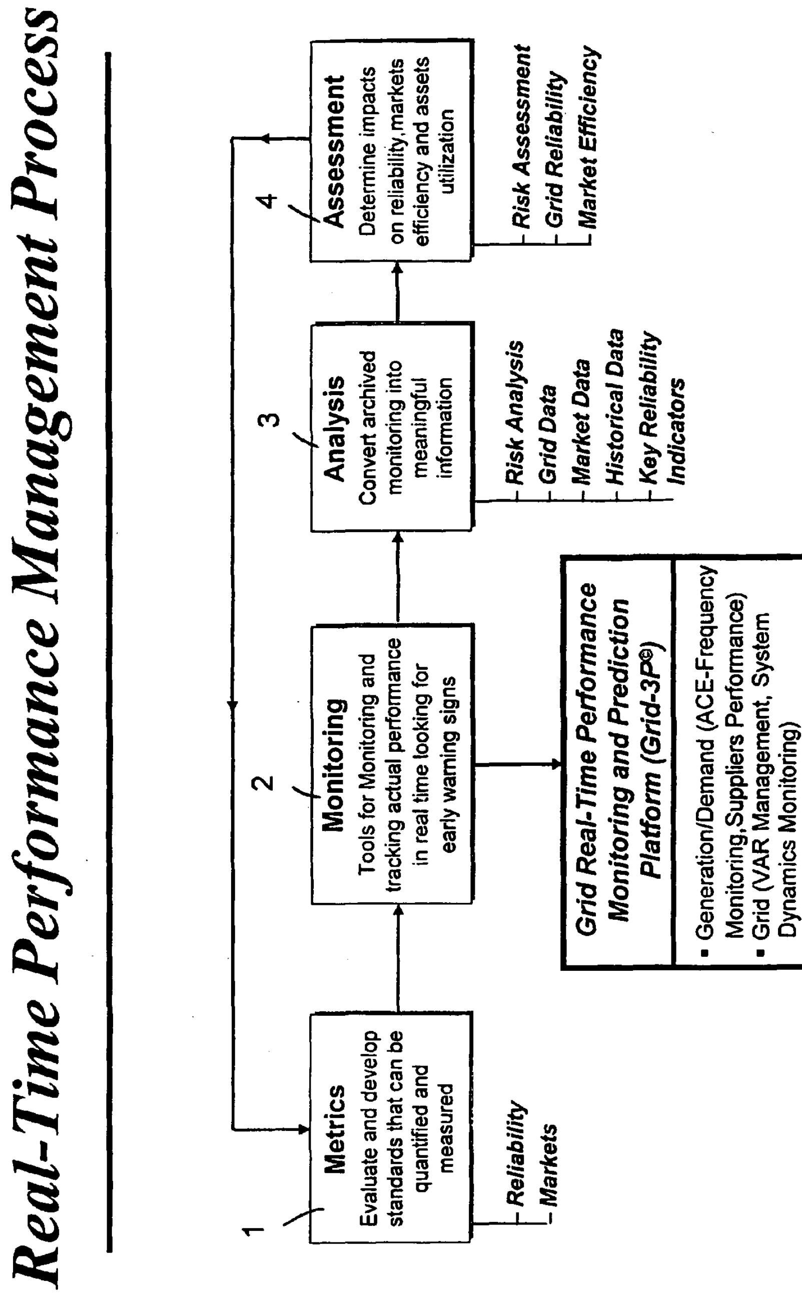
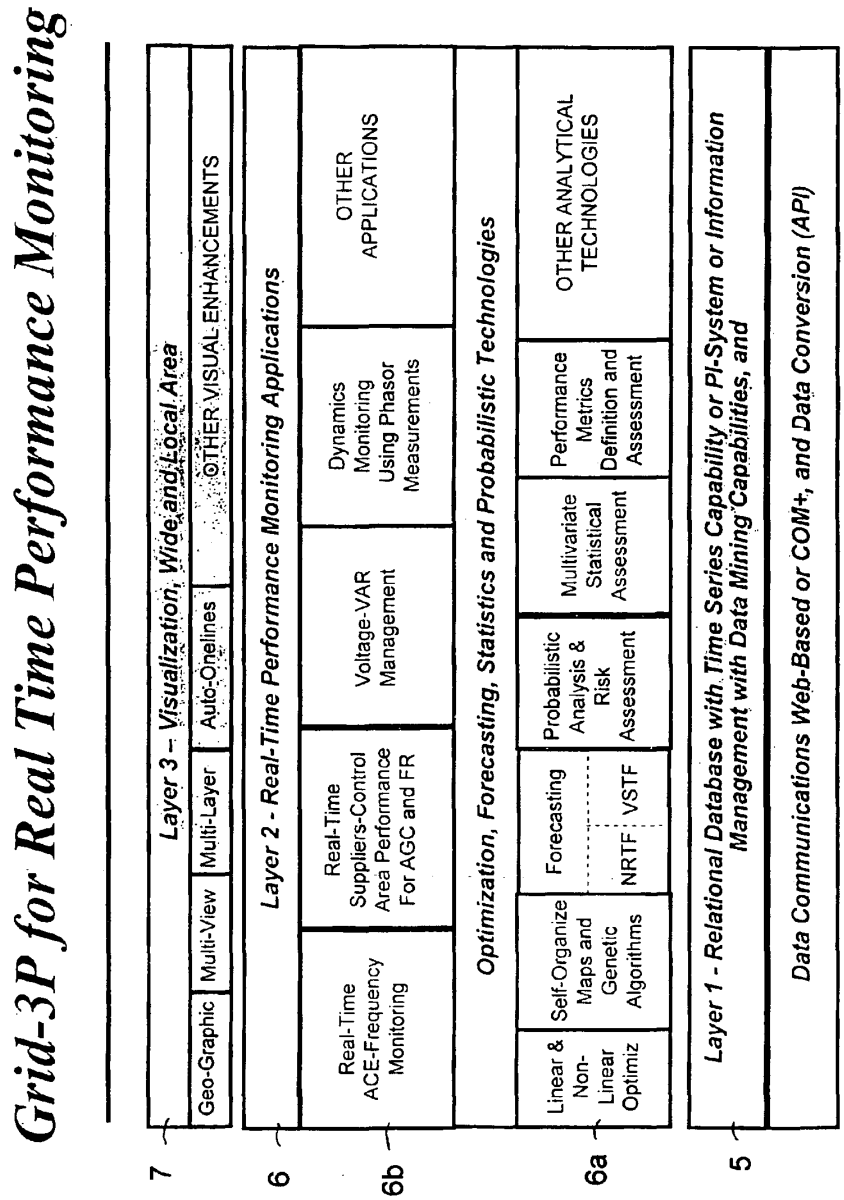

Real-Time Performance Management Process
1
Metrics
Evaluate and develop standards that can be quantified and measured
Reliability
Markets
2
Monitoring
Tools for Monitoring and tracking actual performance in real time looking for early warning signs
3
Analysis
Convert archived monitoring into meaningful information
Risk Analysis
Grid Data
Market Data
Historical Data
Key Reliability Indicators
4
Assessment
Determine impacts on reliability, markets efficiency and assets utilization
Risk Assessment
Grid Reliability
Market Efficiency
Grid Real-Time Performance Monitoring and Prediction Platform (Grid-3P©)
▪ Generation/Demand (ACE-Frequency Monitoring, Suppliers Performance)
▪ Grid (VAR Management, System Dynamics Monitoring)
▪ Markets

FIG. 3



Grid-3P for Real Time Performance Monitoring
7
Layer 3 – Visualization, Wide and Local Area
Geo-Graphic
Multi-View
Multi-Layer
Auto-Onelines
OTHER VISUAL ENHANCEMENTS
6
Layer 2 - Real-Time Performance Monitoring Applications
6b
Real-Time ACE-Frequency Monitoring
Real-Time Suppliers-Control Area Performance For AGC and FR
Voltage-VAR Management
Dynamics Monitoring Using Phasor Measurements
OTHER APPLICATIONS
Optimization, Forecasting, Statistics and Probabilistic Technologies
6a
Linear & Non-Linear Optimiz
Self-Organize Maps and Genetic Algorithms
Forecasting
NRTF
VSTF
Probabilistic Analysis & Risk Assessment
Multivariate Statistical Assessment
Performance Metrics Definition and Assessment
OTHER ANALYTICAL TECHNOLOGIES
5
Layer 1 - Relational Database with Time Series Capability or PI-System or Information Management with Data Mining Capabilities, and
Data Communications Web-Based or COM+, and Data Conversion (API)

FIG. 4

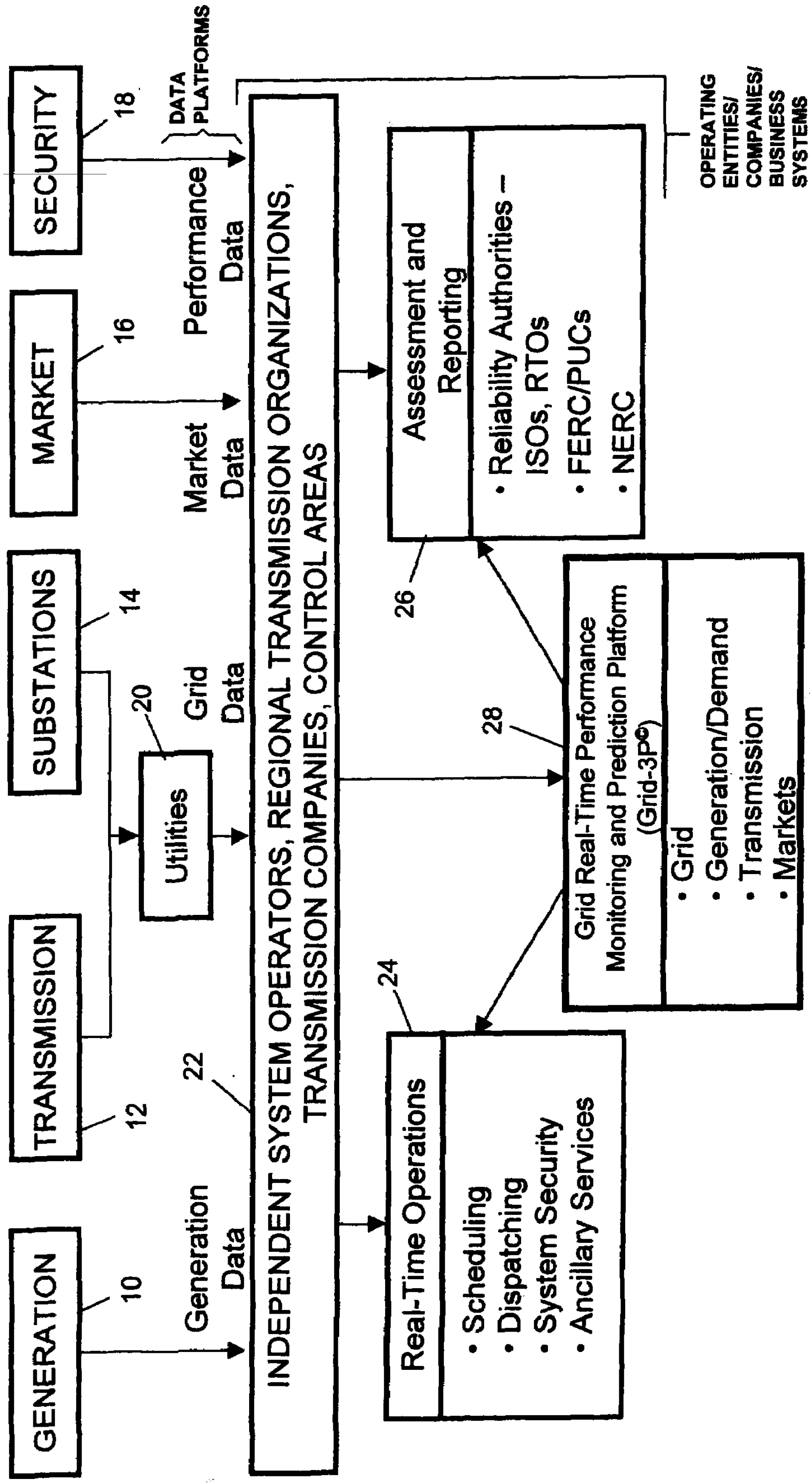

GENERATION
10
TRANSMISSION
12
SUBSTATIONS
14
MARKET
16
SECURITY
18
Utilities
20
Generation Data
22
Grid Data
Market Data
Performance Data
DATA PLATFORMS
INDEPENDENT SYSTEM OPERATORS, REGIONAL TRANSMISSION ORGANIZATIONS, TRANSMISSION COMPANIES, CONTROL AREAS
OPERATING ENTITIES/ COMPANIES/ BUSINESS SYSTEMS
Real-Time Operations
• Scheduling
• Dispatching
• System Security
• Ancillary Services
24
Grid Real-Time Performance Monitoring and Prediction Platform (Grid-3P©)
• Grid
• Generation/Demand
• Transmission
• Markets
28
Assessment and Reporting
• Reliability Authorities – ISOs, RTOs
• FERC/PUCs
• NERC
26

FIG. 5

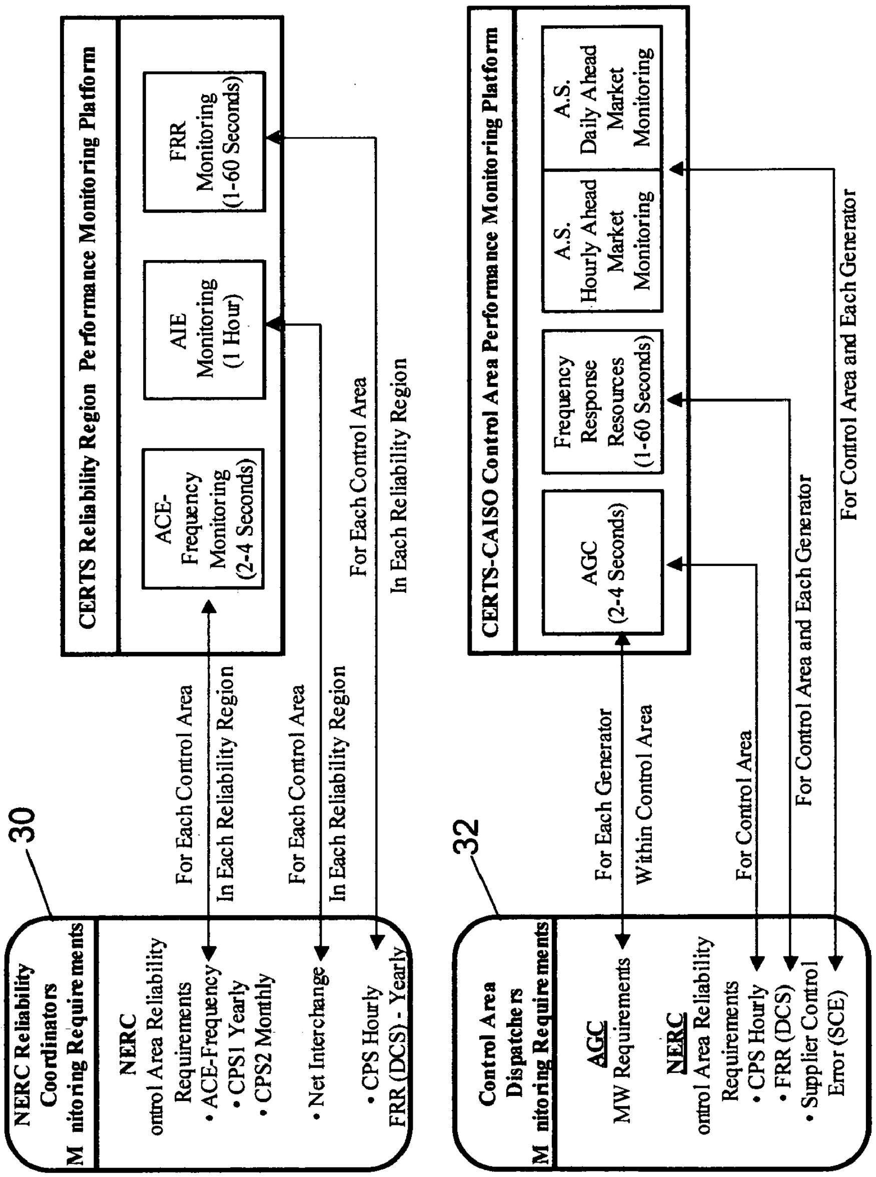

30
NERC Reliability Coordinators Monitoring Requirements
NERC
Control Area Reliability Requirements
• ACE-Frequency
• CPS1 Yearly
• CPS2 Monthly
• Net Interchange
• CPS Hourly
FRR (DCS) - Yearly
For Each Control Area
In Each Reliability Region
For Each Control Area
In Each Reliability Region
For Each Control Area
In Each Reliability Region
CERTS Reliability Region Performance Monitoring Platform
ACE-Frequency Monitoring (2-4 Seconds)
AIE Monitoring (1 Hour)
FRR Monitoring (1-60 Seconds)
32
Control Area Dispatchers Monitoring Requirements
AGC
MW Requirements
NERC
Control Area Reliability Requirements
• CPS Hourly
• FRR (DCS)
• Supplier Control Error (SCE)
For Each Generator
Within Control Area
For Control Area
For Control Area and Each Generator
For Control Area and Each Generator
CERTS-CAISO Control Area Performance Monitoring Platform
AGC (2-4 Seconds)
Frequency Response Resources (1-60 Seconds)
A.S. Hourly Ahead Market Monitoring
A.S. Daily Ahead Market Monitoring

FIG. 6

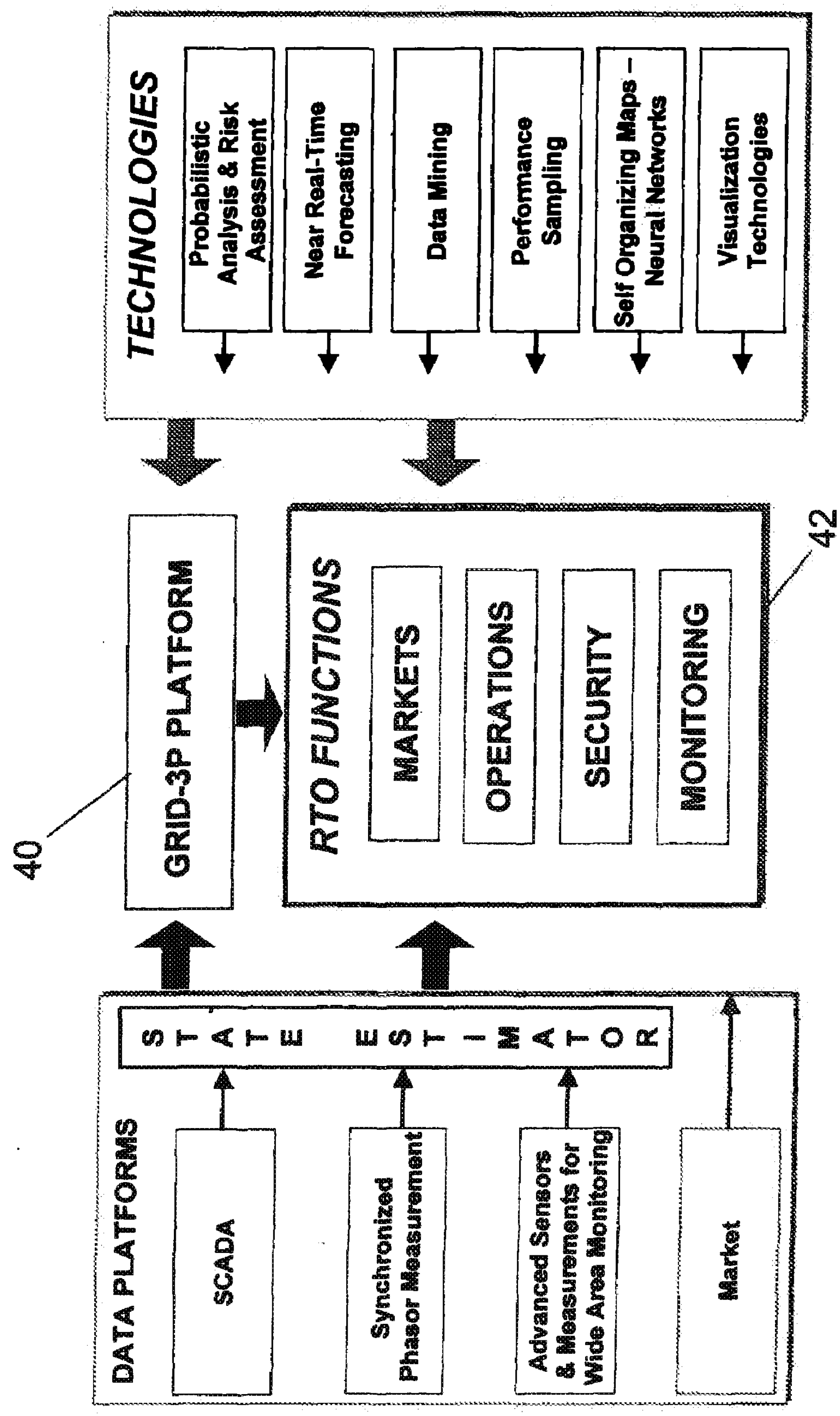

TECHNOLOGIES
Probabilistic Analysis & Risk Assessment
Near Real-Time Forecasting
Data Mining
Performance Sampling
Self Organizing Maps – Neural Networks
Visualization Technologies
40
GRID-3P PLATFORM
RTO FUNCTIONS
MARKETS
OPERATIONS
SECURITY
MONITORING
42
DATA PLATFORMS
STATE ESTIMATOR
SCADA
Synchronized Phasor Measurement
Advanced Sensors & Measurements for Wide Area Monitoring
Market

FIG. 7

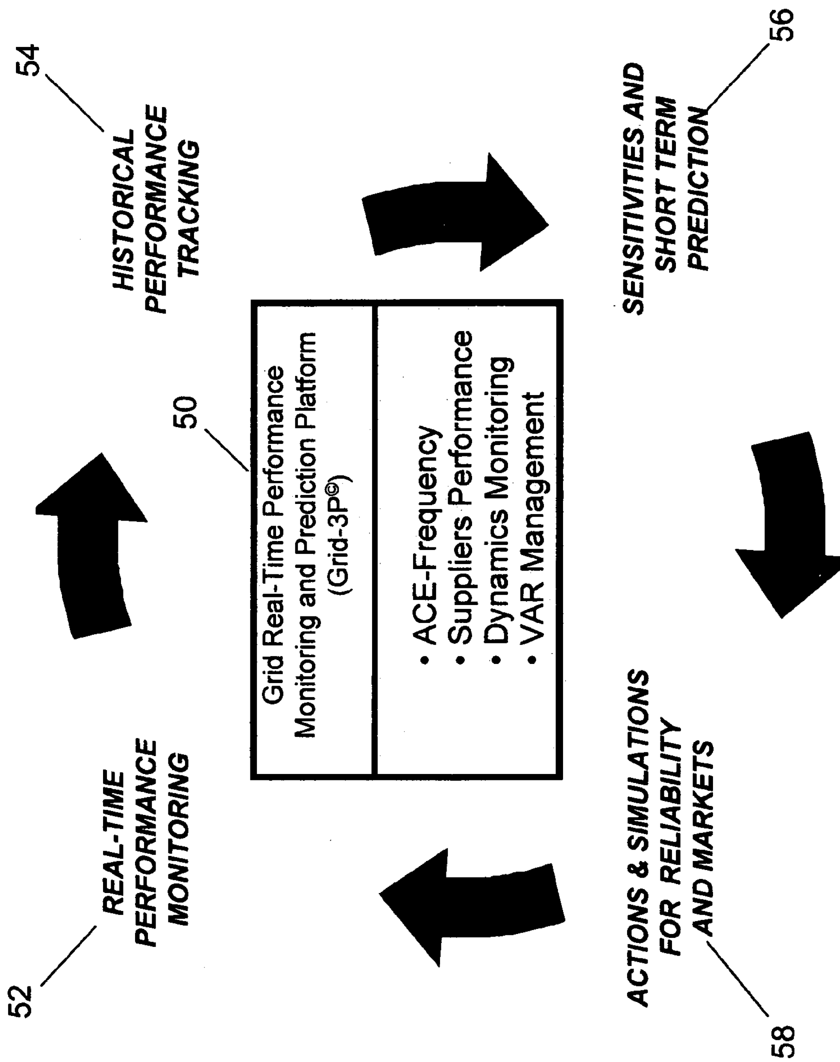
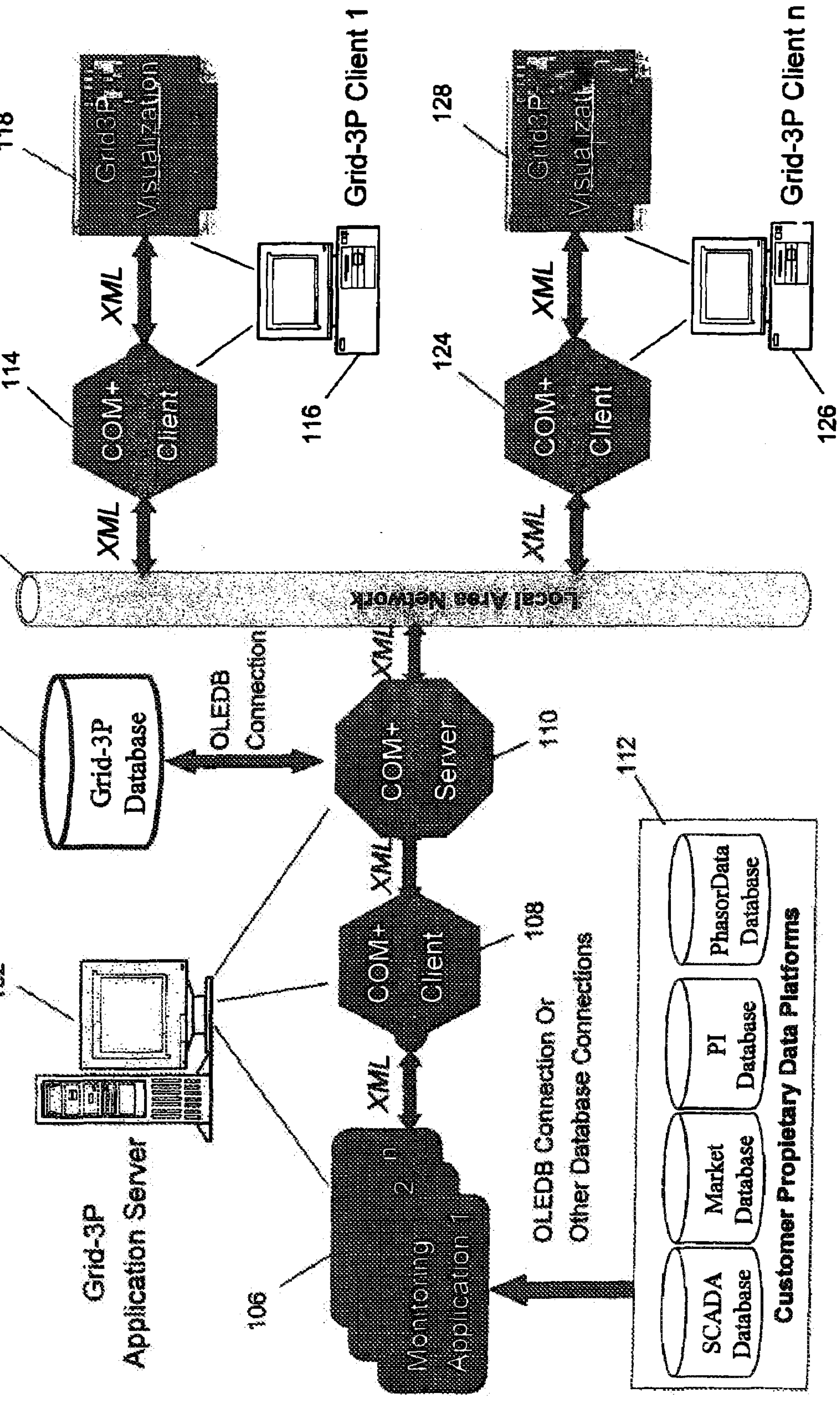

54
HISTORICAL PERFORMANCE TRACKING
56
SENSITIVITIES AND SHORT TERM PREDICTION
50
Grid Real-Time Performance Monitoring and Prediction Platform (Grid-3P©)
• ACE-Frequency
• Suppliers Performance
• Dynamics Monitoring
• VAR Management
52
REAL-TIME PERFORMANCE MONITORING
58
ACTIONS & SIMULATIONS FOR RELIABILITY AND MARKETS

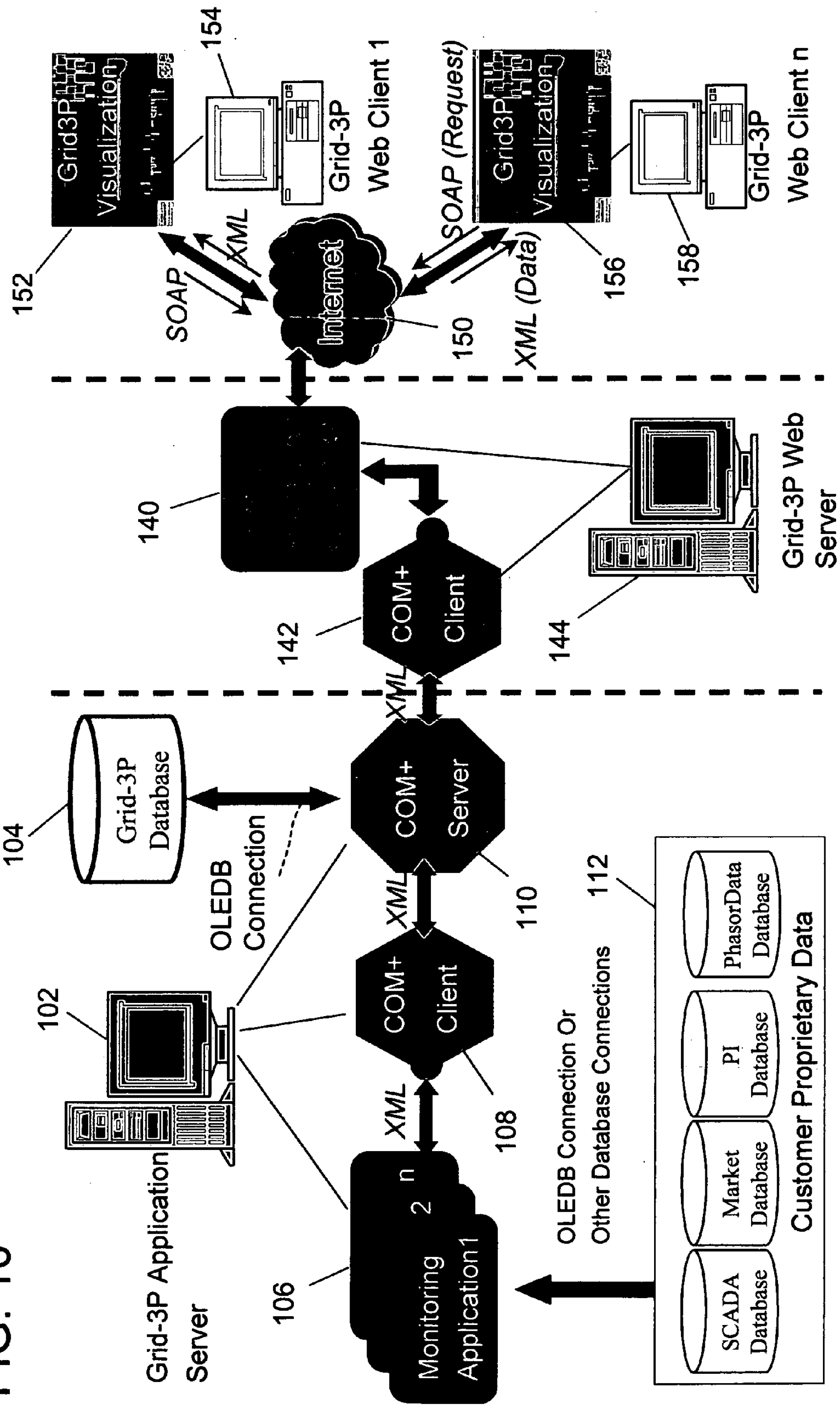
FIG. 8

FIG. 9



Grid-3P Application Server
102
104
Grid-3P Database
OLEDB Connection
COM+ Server
110
XML
COM+ Client
108
XML
Monitoring Application 1
2
n
106
OLEDB Connection Or Other Database Connections
112
SCADA Database
Market Database
PI Database
PhasorData Database
Customer Proprietary Data Platforms
Local Area Network
100
XML
COM+ Client
114
XML
Grid3P Visualization
118
116
Grid-3P Client 1
XML
COM+ Client
124
XML
128
126
Grid-3P Client n

FIG. 10


Grid3P Visualization
152
154
Grid-3P Web Client 1
SOAP
XML
Internet
150
SOAP (Request)
XML (Data)
Grid3P Visualization
156
158
Grid-3P Web Client n
140
142
COM+ Client
144
Grid-3P Web Server
XML
104
Grid-3P Database
OLEDB Connection
COM+ Server
110
112
102
XML
COM+ Client
108
XML
Grid-3P Application Server
106
Monitoring Application1
2
n
OLEDB Connection Or Other Database Connections
SCADA Database
Market Database
PI Database
PhasorData Database
Customer Proprietary Data

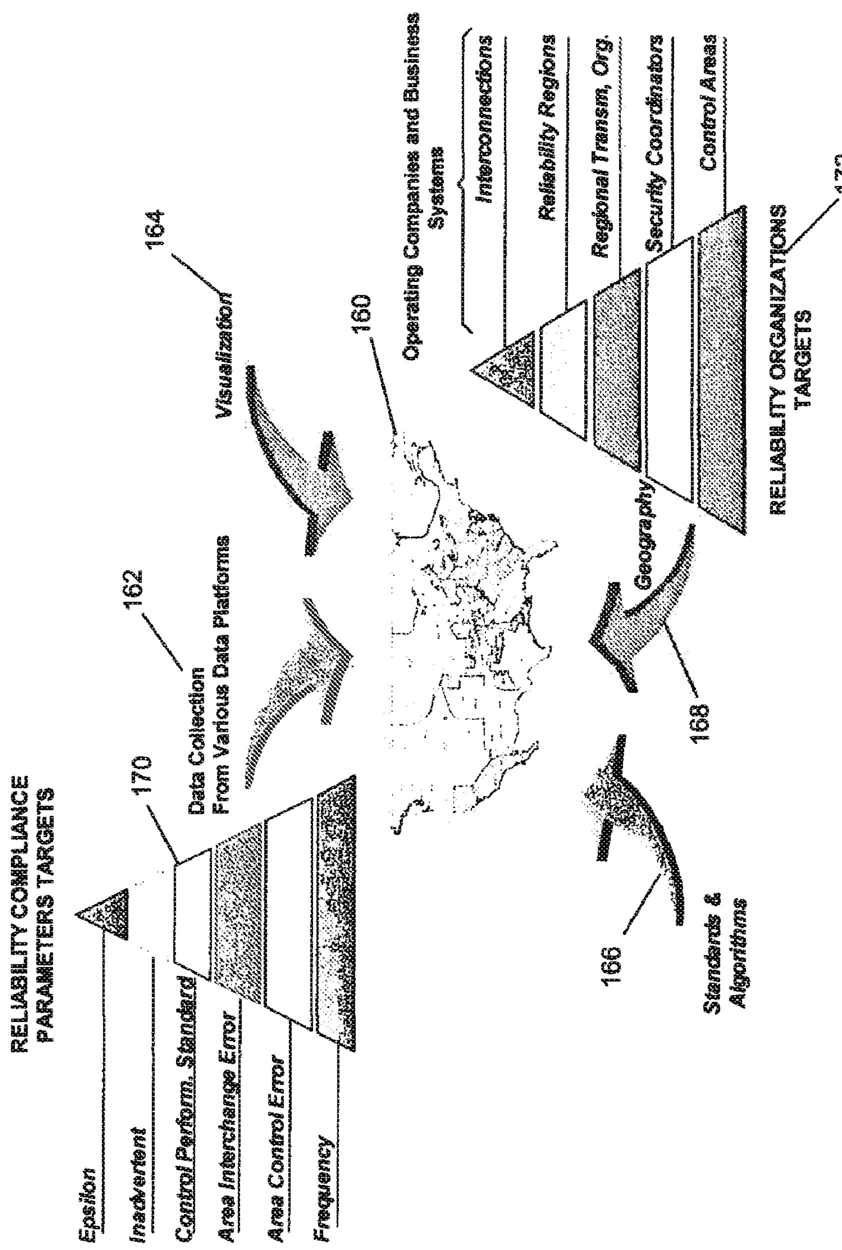

RELIABILITY COMPLIANCE PARAMETERS TARGETS
170
Epsilon
Inadvertent
Control Perform. Standard
Area Interchange Error
Area Control Error
Frequency
162
Data Collection From Various Data Platforms
164
Visualization
160
Operating Companies and Business Systems
Interconnections
Reliability Regions
Regional Transm, Org.
Security Coordinators
Control Areas
172
RELIABILITY ORGANIZATIONS TARGETS
Geography
168
166
Standards & Algorithms

FIG. 11

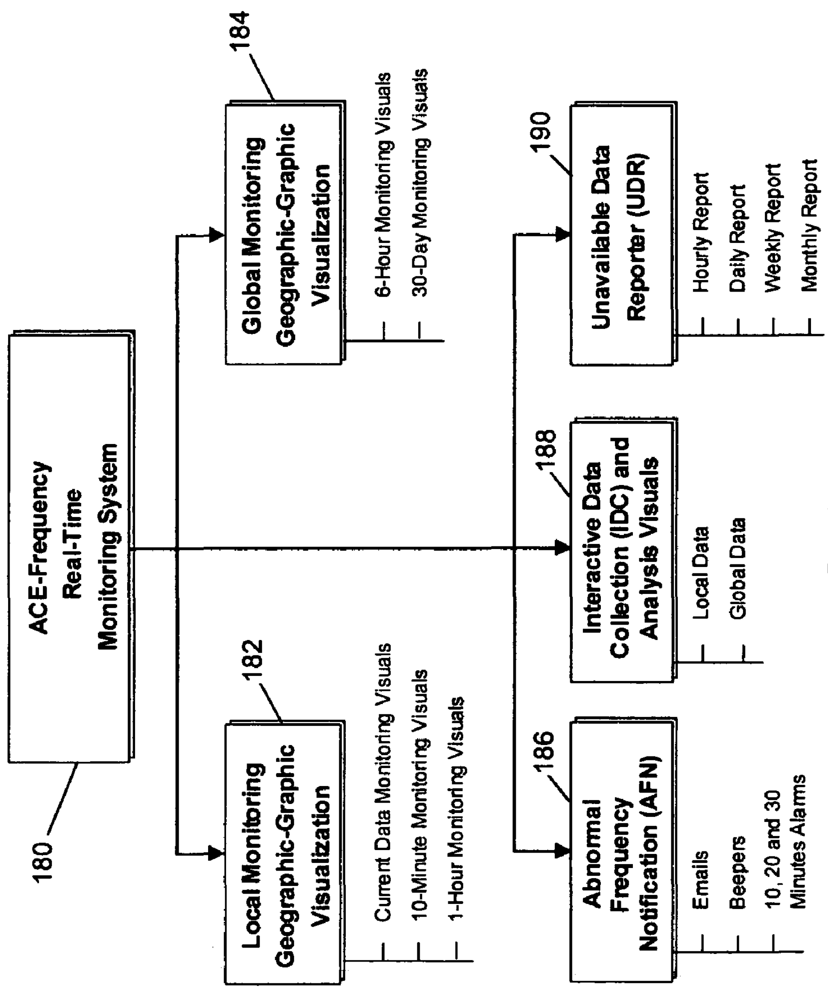
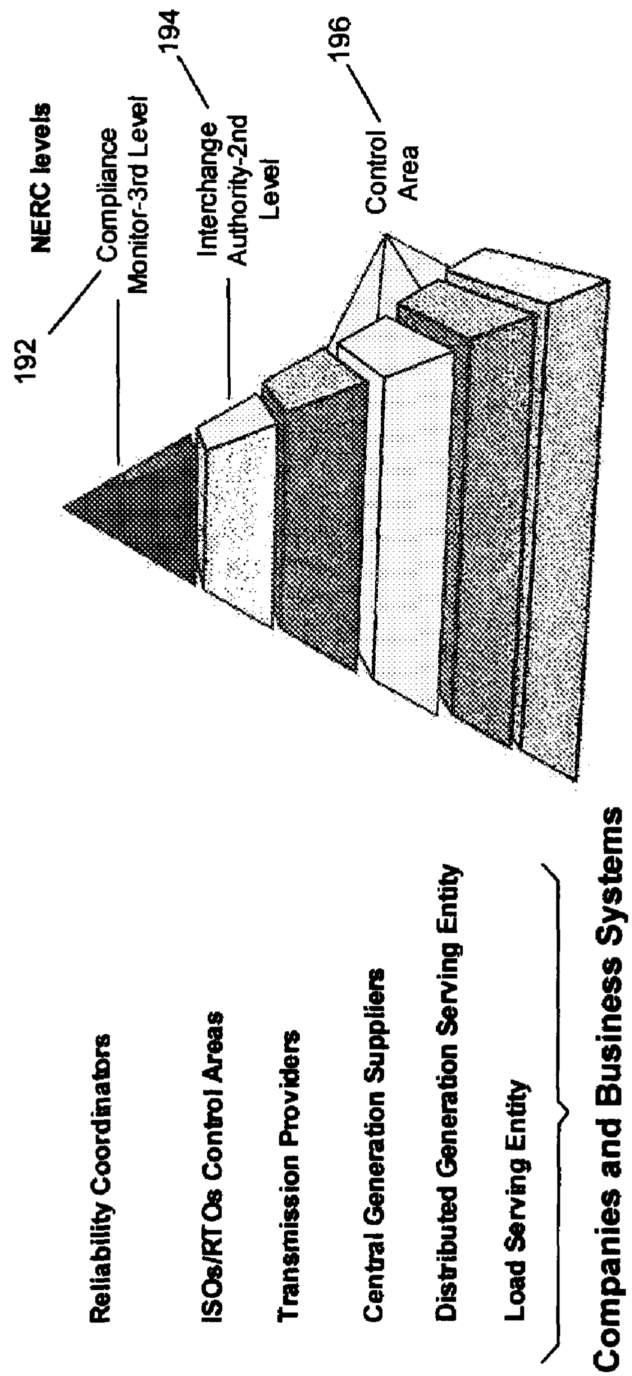
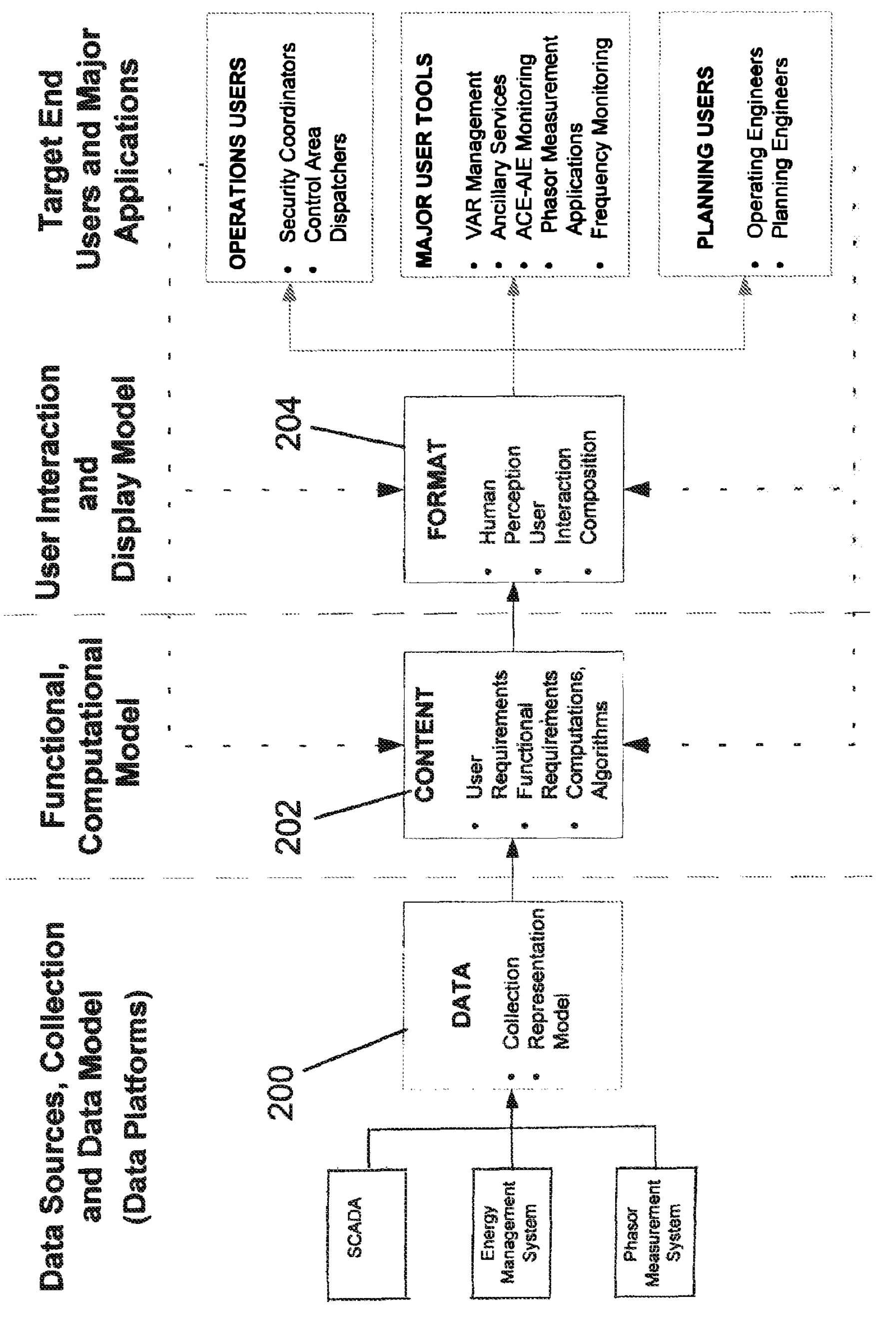

ACE-Frequency Real-Time Monitoring System
180
Local Monitoring Geographic-Graphic Visualization
182
Current Data Monitoring Visuals
10-Minute Monitoring Visuals
1-Hour Monitoring Visuals
Global Monitoring Geographic-Graphic Visualization
184
6-Hour Monitoring Visuals
30-Day Monitoring Visuals
Abnormal Frequency Notification (AFN)
186
Emails
Beepers
10, 20 and 30 Minutes Alarms
Interactive Data Collection (IDC) and Analysis Visuals
188
Local Data
Global Data
Unavailable Data Reporter (UDR)
190
Hourly Report
Daily Report
Weekly Report
Monthly Report

FIG. 12



NERC levels
192
Compliance Monitor-3rd Level
194
Interchange Authority-2nd Level
196
Control Area
Reliability Coordinators
ISOs/RTOs Control Areas
Transmission Providers
Central Generation Suppliers
Distributed Generation Serving Entity
Load Serving Entity
Companies and Business Systems

FIG. 13



Data Sources, Collection and Data Model (Data Platforms)
SCADA
Energy Management System
Phasor Measurement System
200
DATA
• Collection
• Representation Model
Functional, Computational Model
202
CONTENT
• User Requirements
• Functional Requirements
• Computations, Algorithms
User Interaction and Display Model
204
FORMAT
• Human Perception
• User Interaction
• Composition
Target End Users and Major Applications
OPERATIONS USERS
• Security Coordinators
• Control Area Dispatchers
MAJOR USER TOOLS
• VAR Management
• Ancillary Services
• ACE-AIE Monitoring
• Phasor Measurement Applications
• Frequency Monitoring
PLANNING USERS
• Operating Engineers
• Planning Engineers

FIG. 14

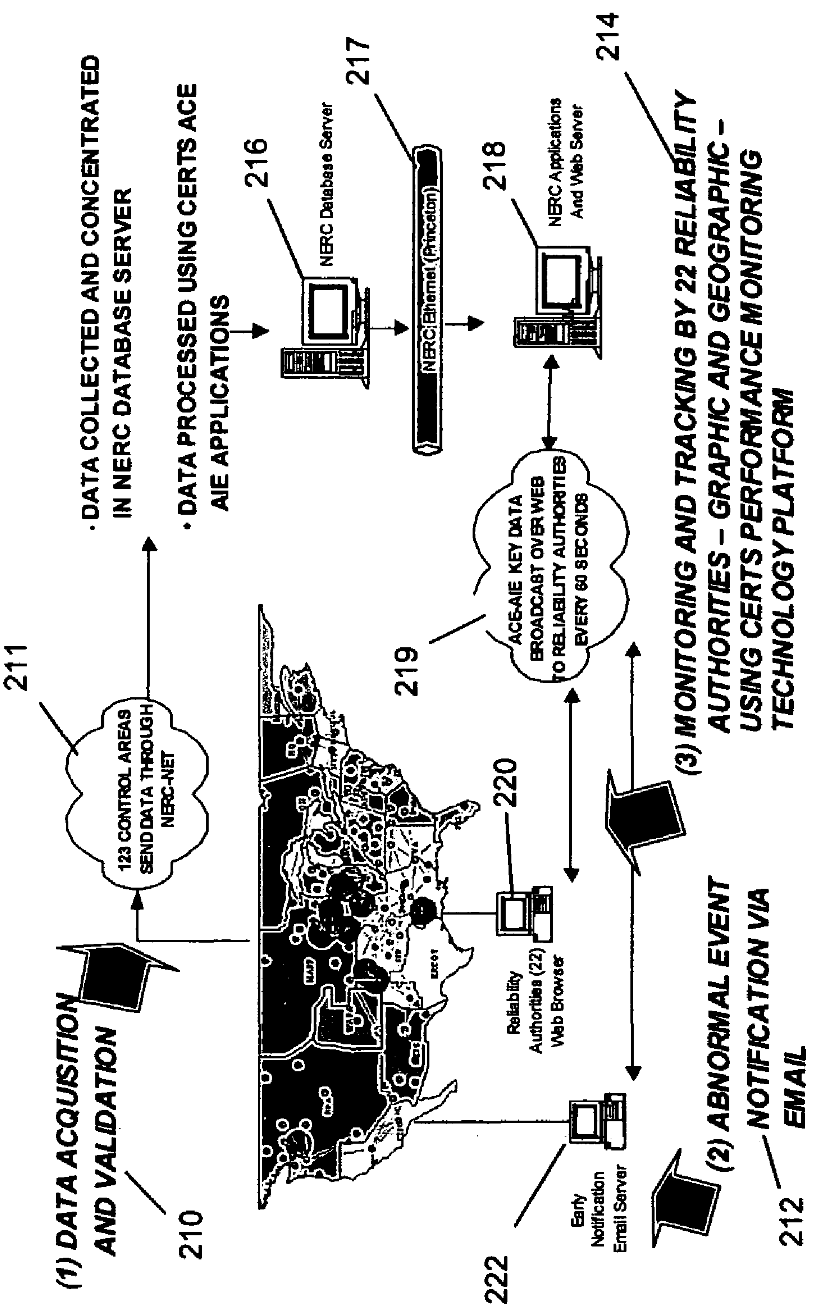

(1) DATA ACQUISITION AND VALIDATION
210
211
123 CONTROL AREAS SEND DATA THROUGH NERC-NET
· DATA COLLECTED AND CONCENTRATED IN NERC DATABASE SERVER
· DATA PROCESSED USING CERTS ACE AIE APPLICATIONS
216
NERC Database Server
217
NERC Ethernet (Princeton)
218
NERC Applications And Web Server
214
219
ACE-AIE KEY DATA BROADCAST OVER WEB TO RELIABILITY AUTHORITIES EVERY 60 SECONDS
220
Reliability Authorities (22) Web Browser
222
Early Notification Email Server
(2) ABNORMAL EVENT NOTIFICATION VIA EMAIL
212
(3) MONITORING AND TRACKING BY 22 RELIABILITY AUTHORITIES – GRAPHIC AND GEOGRAPHIC – USING CERTS PERFORMANCE MONITORING TECHNOLOGY PLATFORM

FIG. 15

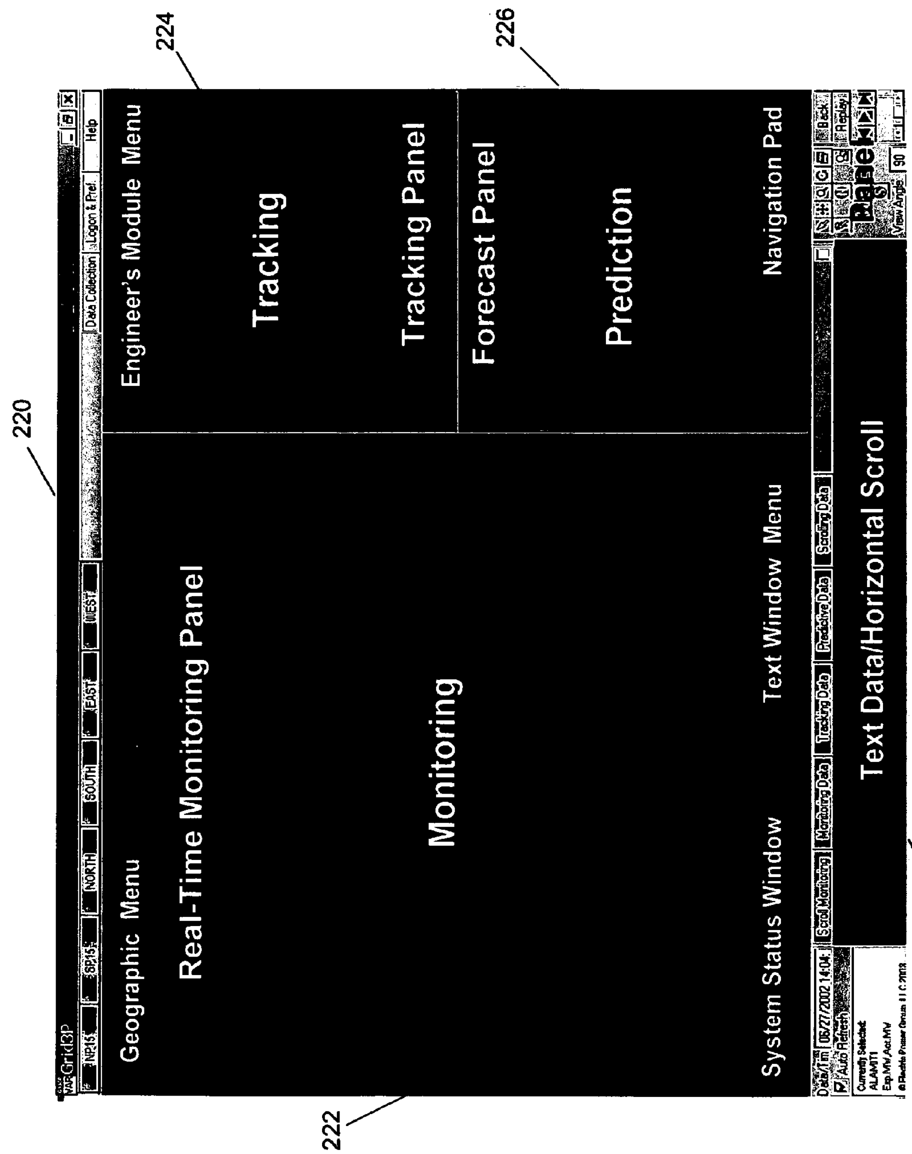

220
222
224
226
228
Grid3P
NORTH
SOUTH
EAST
WEST
Data Collection
Logon & Pref
Help
Geographic Menu
Real-Time Monitoring Panel
Monitoring
Engineer's Module Menu
Tracking
Tracking Panel
Forecast Panel
Prediction
Navigation Pad
System Status Window
Text Window Menu
Monitoring Data
Tracking Data
Predictive Data
Scrolling Data
Text Data/Horizontal Scroll

FIG. 16

230

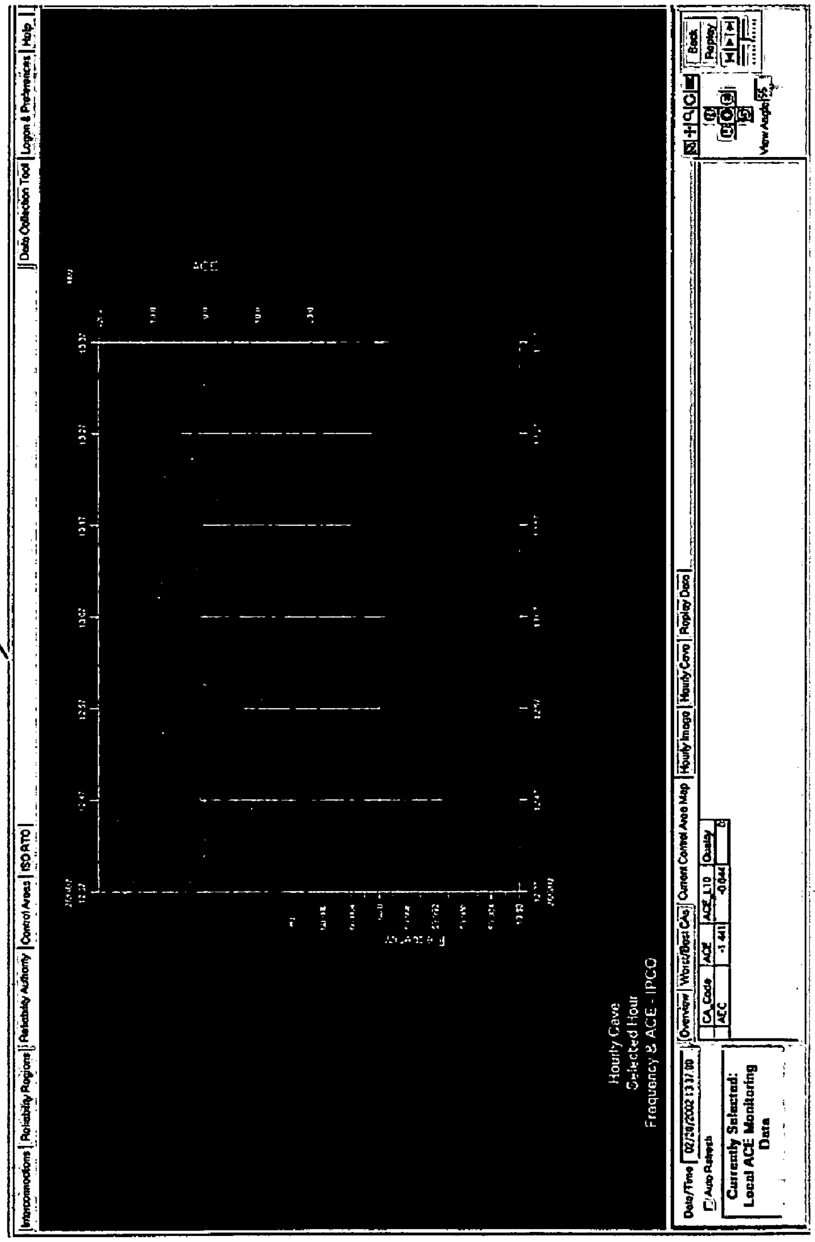


FIG. 17

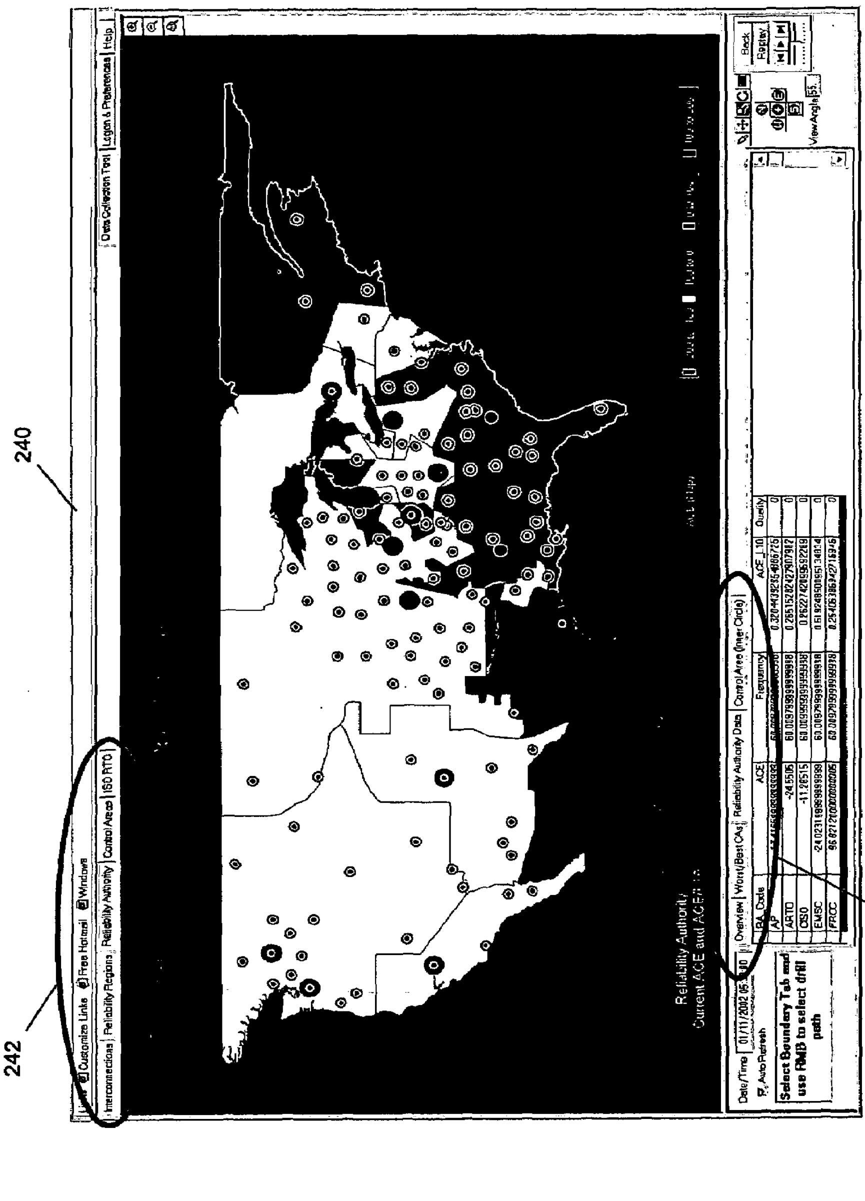
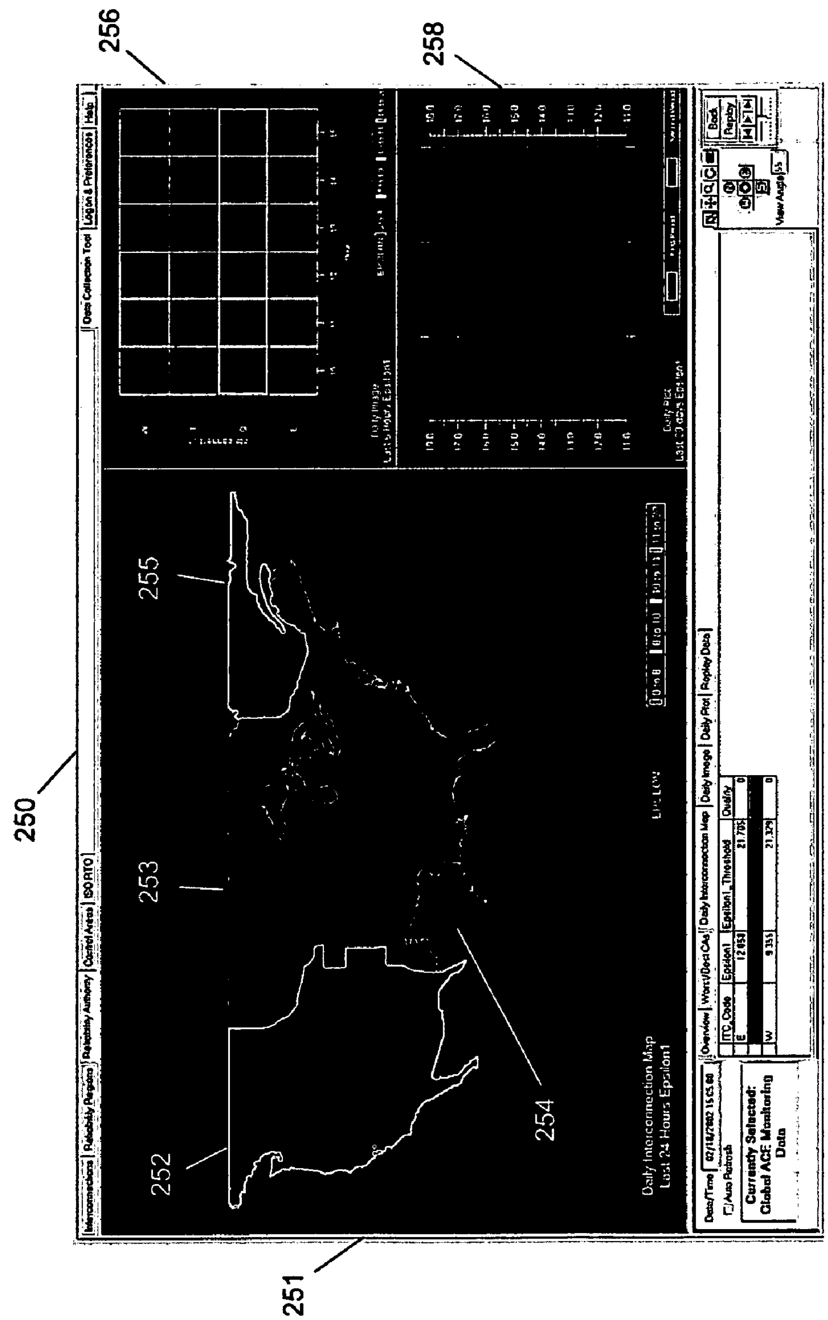


FIG. 18



256
258
250
251
252
253
254
255
Daily Interconnection Map
Last 24 Hours Epsilon1
Currently Selected:
Global ACE Monitoring Data

FIG. 19

260

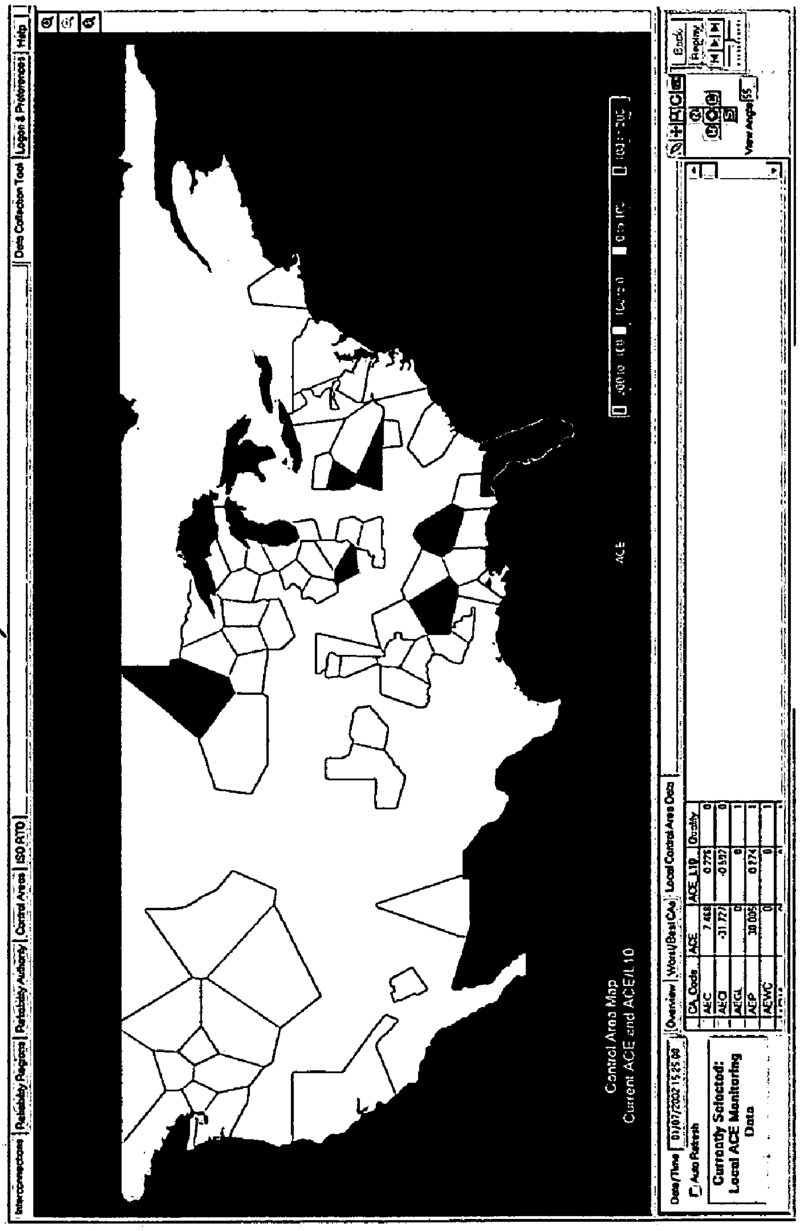

Control Area Map
Current ACE and ACE/L10
Currently Selected:
Local ACE Monitoring
Data

FIG.20

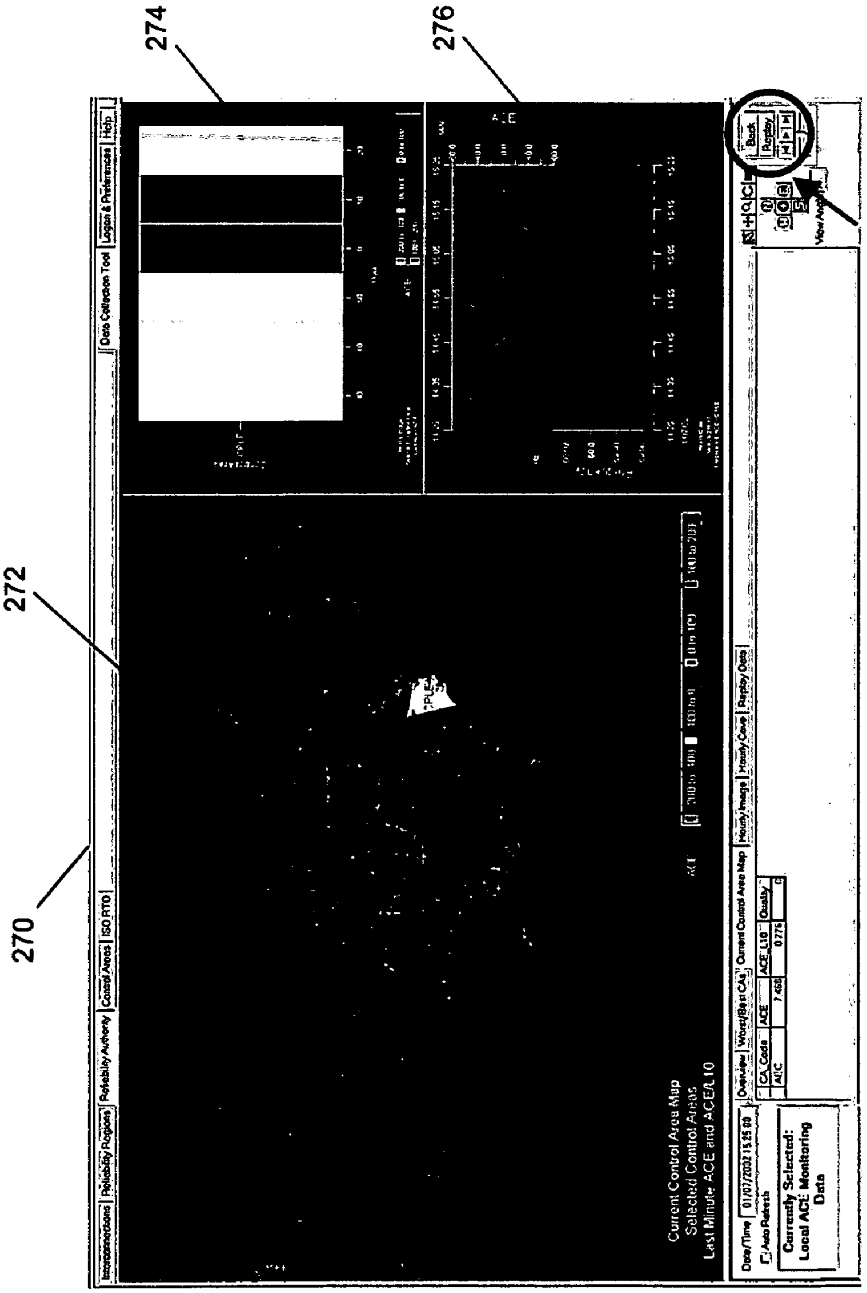

270
272
274
276
Current Control Area Map
Selected Control Areas
Last Minute ACE and ACE/L10
Currently Selected:
Local ACE Monitoring
Data
Back
Replay

FIG. 21

280

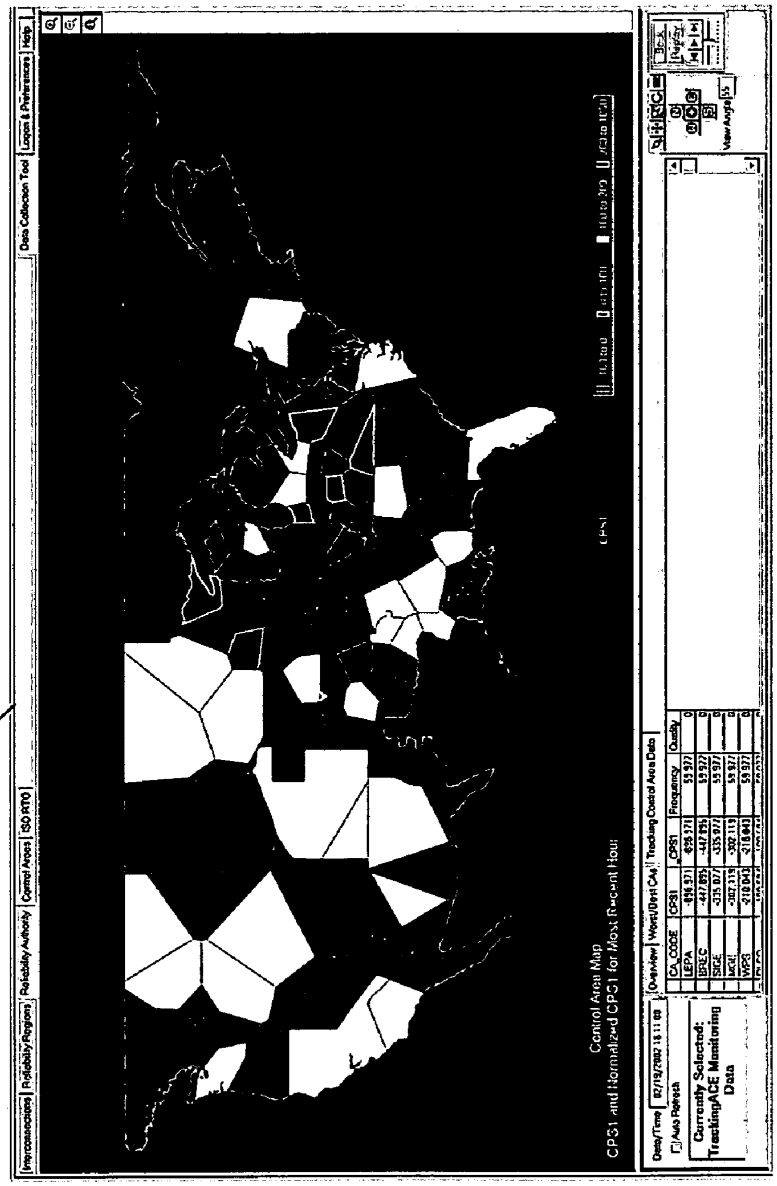

Control Area Map
CPS1 and Normalized CPS1 for Most Recent Hour

FIG. 22

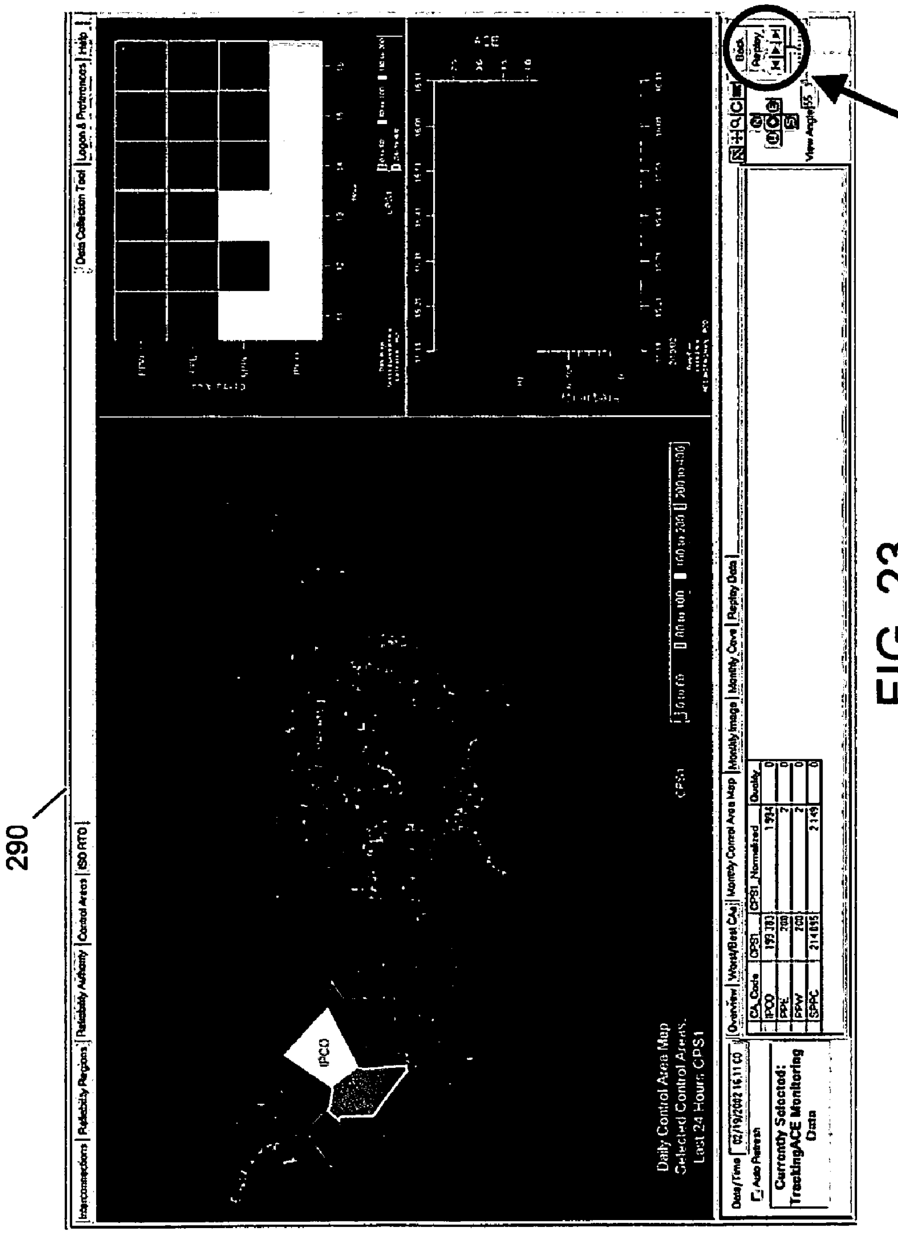

290
Daily Control Area Map
Selected Control Areas:
Last 24 Hours: CPS1
Currently Selected:
TrackingACE Monitoring Data
Overview
Replay Data
Help

FIG. 23

300

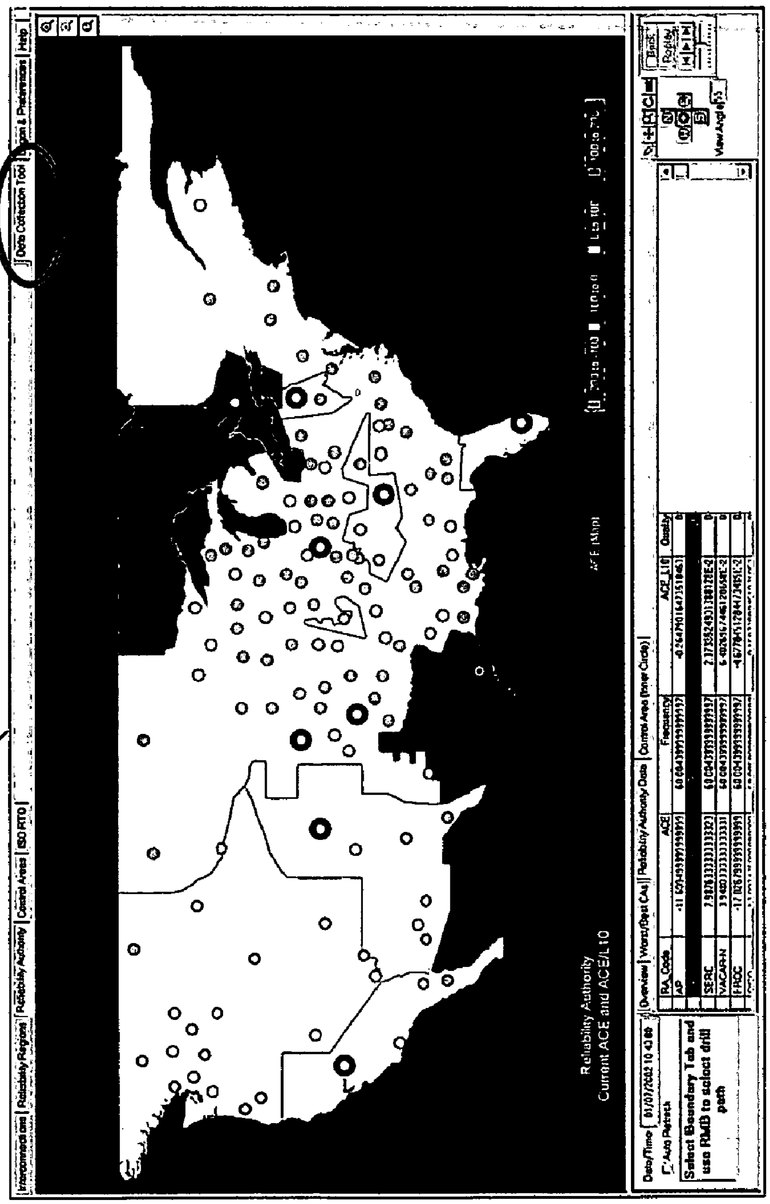


FIG. 24

310

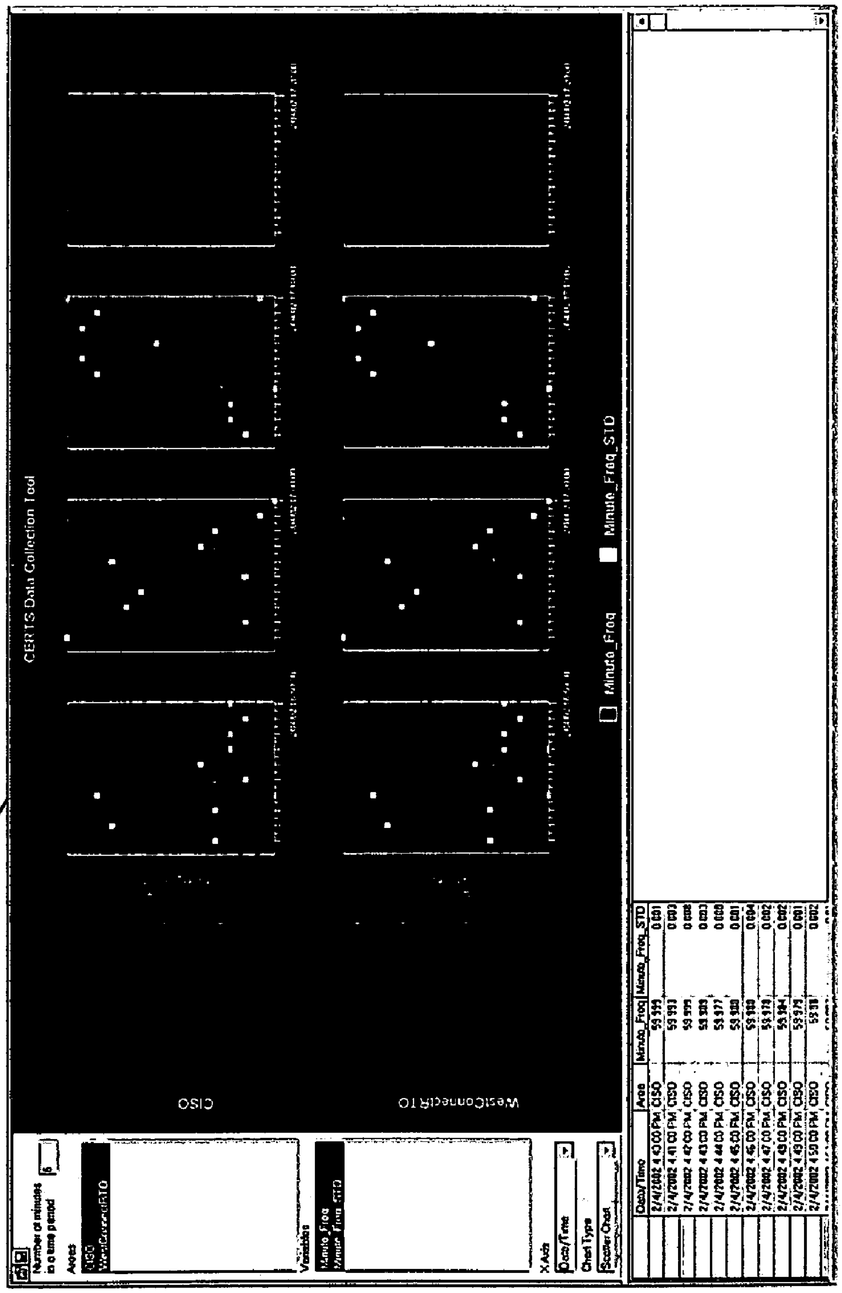

CERTS Data Collection Tool
Minute_Freq
Minute_Freq_STD
CISO
WestConnectRTO

FIG. 25

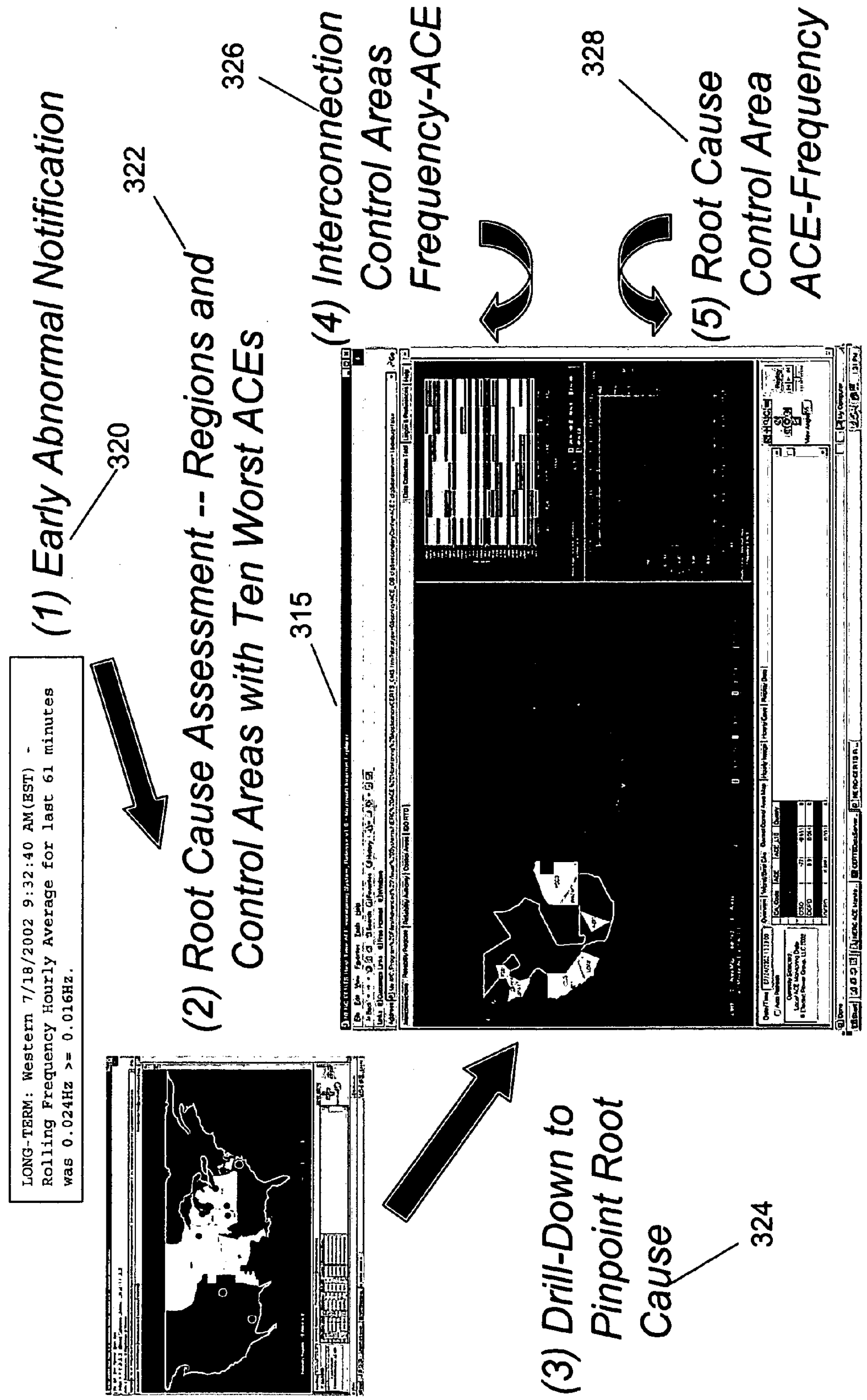
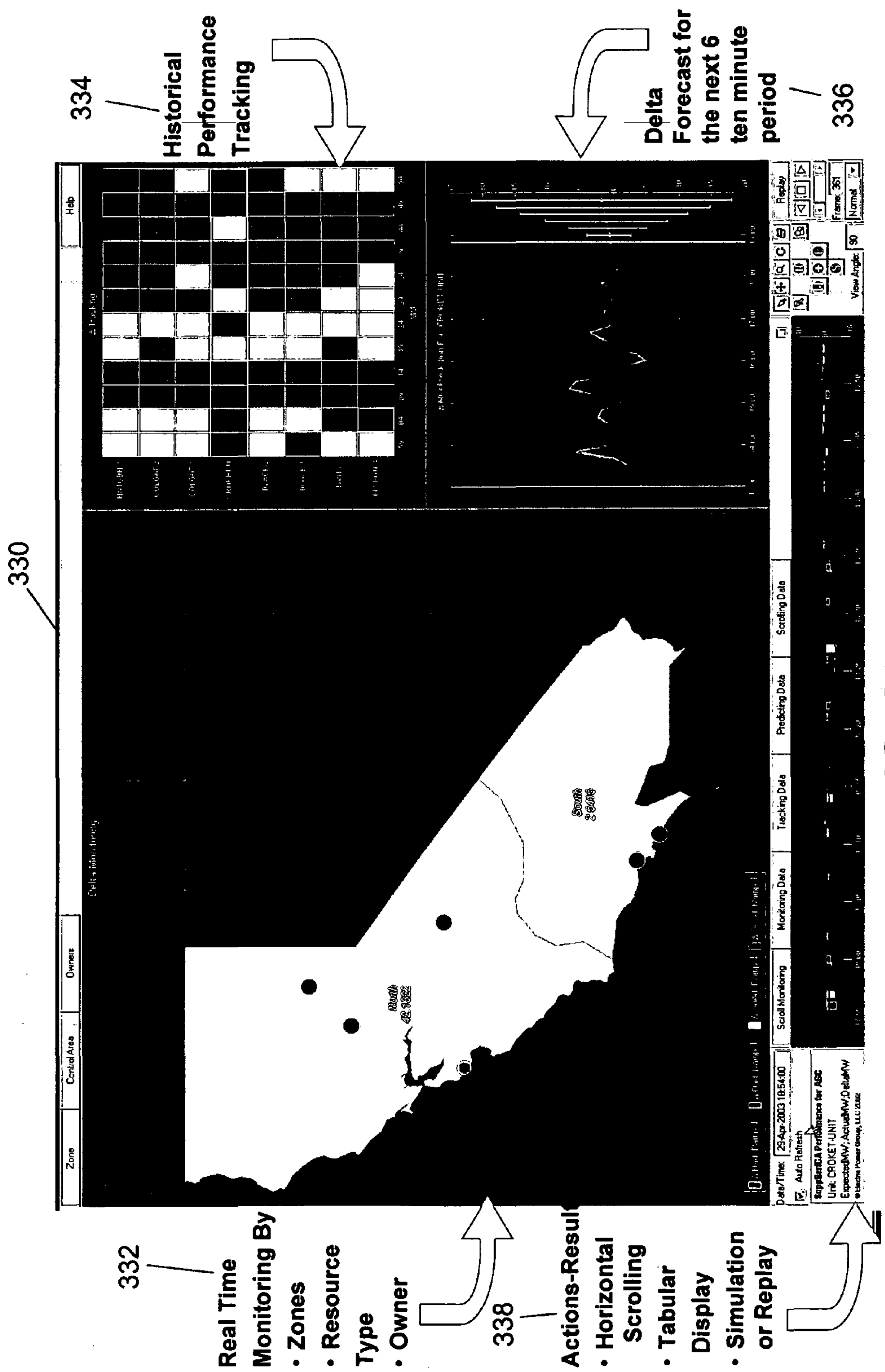

LONG-TERM: Western 7/18/2002 9:32:40 AM(EST) - Rolling Frequency Hourly Average for last 61 minutes was 0.024Hz >= 0.016Hz.
(1) Early Abnormal Notification
320
(2) Root Cause Assessment -- Regions and Control Areas with Ten Worst ACEs
322
315
(3) Drill-Down to Pinpoint Root Cause
324
(4) Interconnection Control Areas Frequency-ACE
326
(5) Root Cause Control Area ACE-Frequency
328

FIG. 26



334
Historical Performance Tracking
Delta Forecast for the next 6 ten minute period
336
330
Zone
Control Area
Owners
Help
Scroll Monitoring
Monitoring Data
Tracking Data
Predicting Data
Scrolling Data
Replay
332
Real Time Monitoring By
· Zones
· Resource Type
· Owner
338
Actions-Resul
· Horizontal Scrolling
· Tabular Display
· Simulation or Replay

FIG. 27

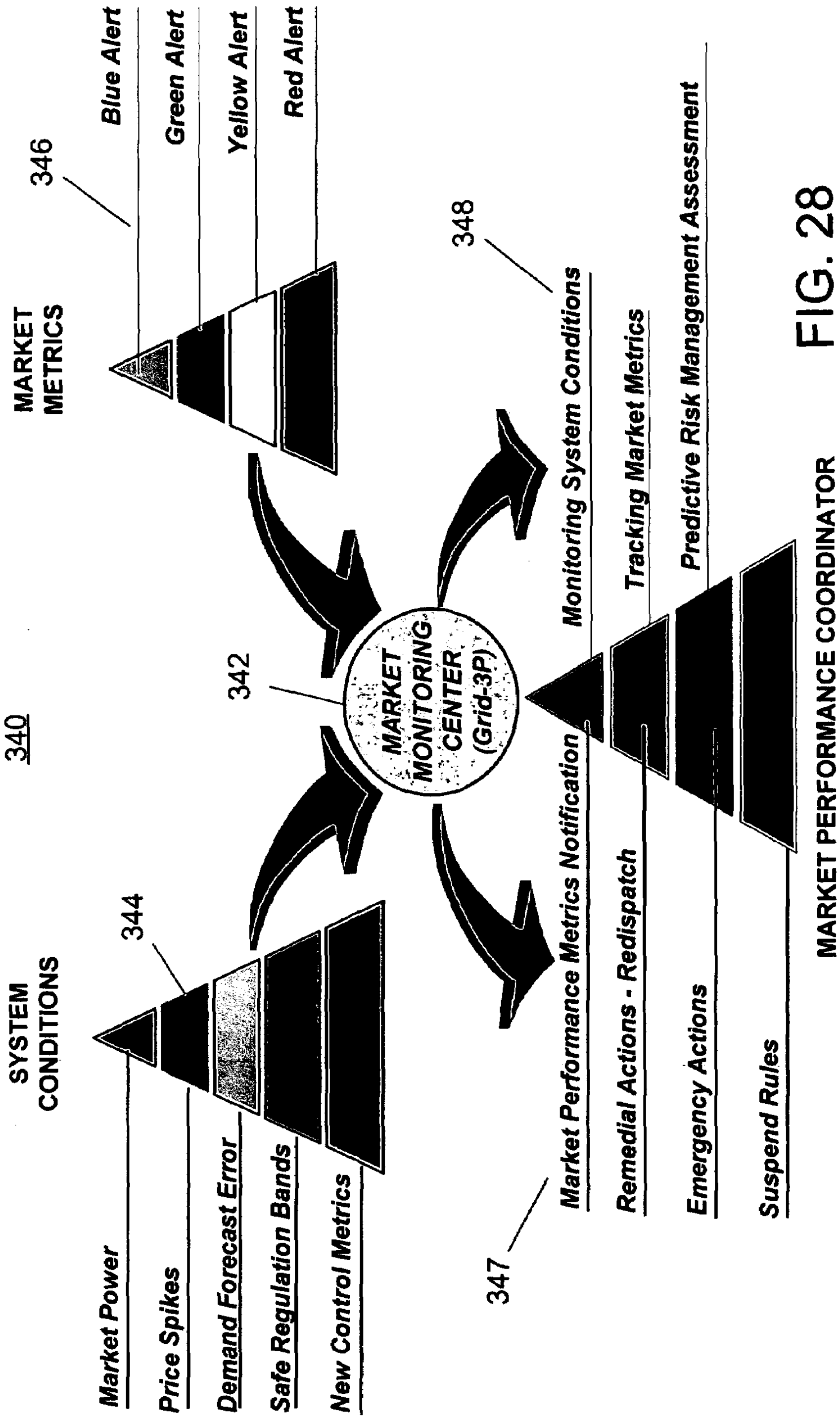
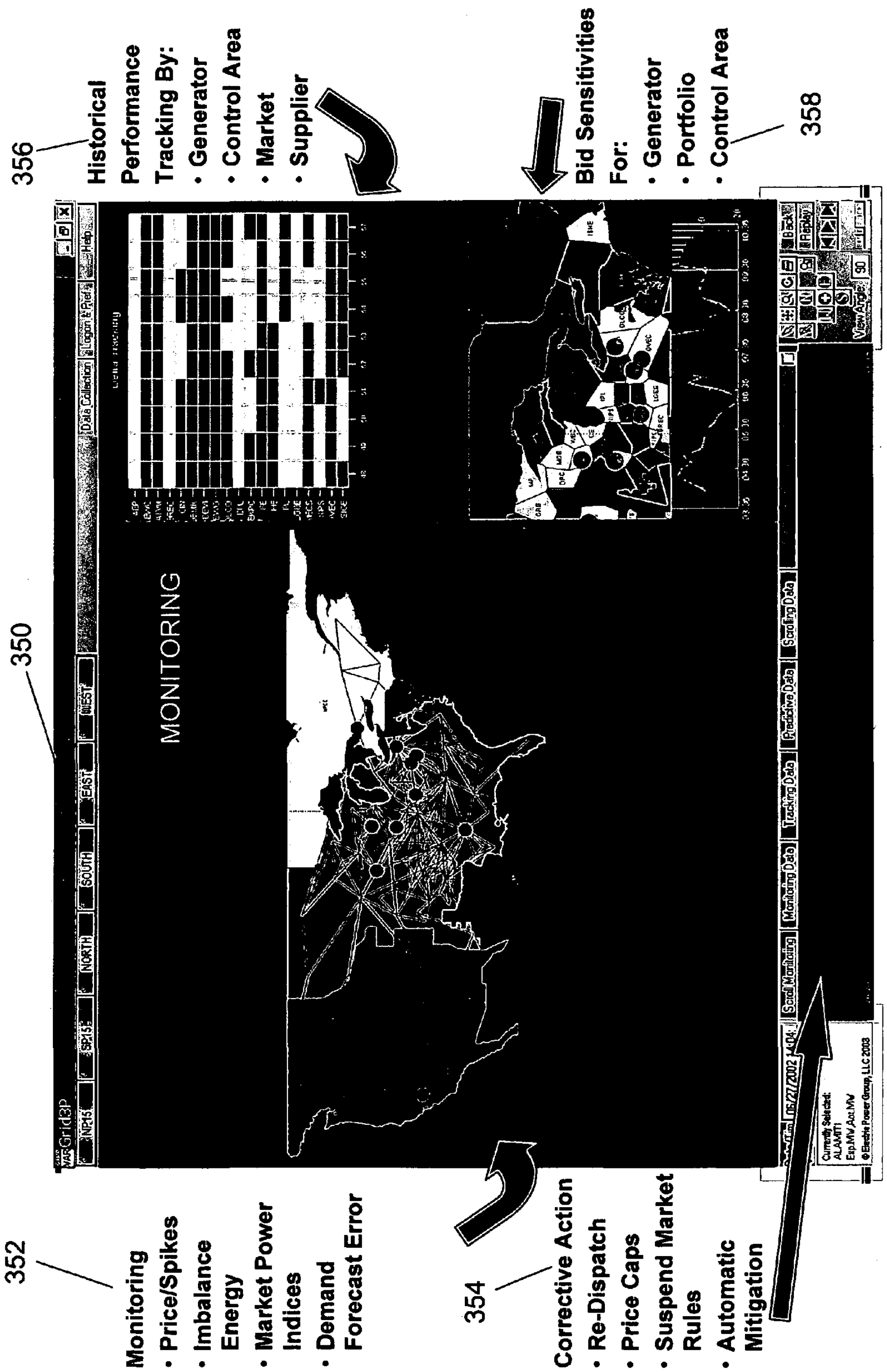

340
SYSTEM CONDITIONS
344
Market Power
Price Spikes
Demand Forecast Error
Safe Regulation Bands
New Control Metrics
MARKET METRICS
346
Blue Alert
Green Alert
Yellow Alert
Red Alert
342
MARKET MONITORING CENTER (Grid-3P)
348
Monitoring System Conditions
Tracking Market Metrics
Predictive Risk Management Assessment
347
Market Performance Metrics Notification
Remedial Actions - Redispatch
Emergency Actions
Suspend Rules
MARKET PERFORMANCE COORDINATOR

FIG. 28



356
Historical Performance Tracking By:
• Generator
• Control Area
• Market
• Supplier
Bid Sensitivities For:
• Generator
• Portfolio
• Control Area
358
350
MONITORING
Grid3P
NORTH
SOUTH
EAST
WEST
Data Collection
Help
Serial Monitoring
Monitoring Data
Tracking Data
Predictive Data
Scrolling Data
View Angle
Currently Selected:
352
Monitoring
• Price/Spikes
• Imbalance Energy
• Market Power Indices
• Demand Forecast Error
354
Corrective Action
• Re-Dispatch
• Price Caps
• Suspend Market Rules
• Automatic Mitigation

FIG. 29

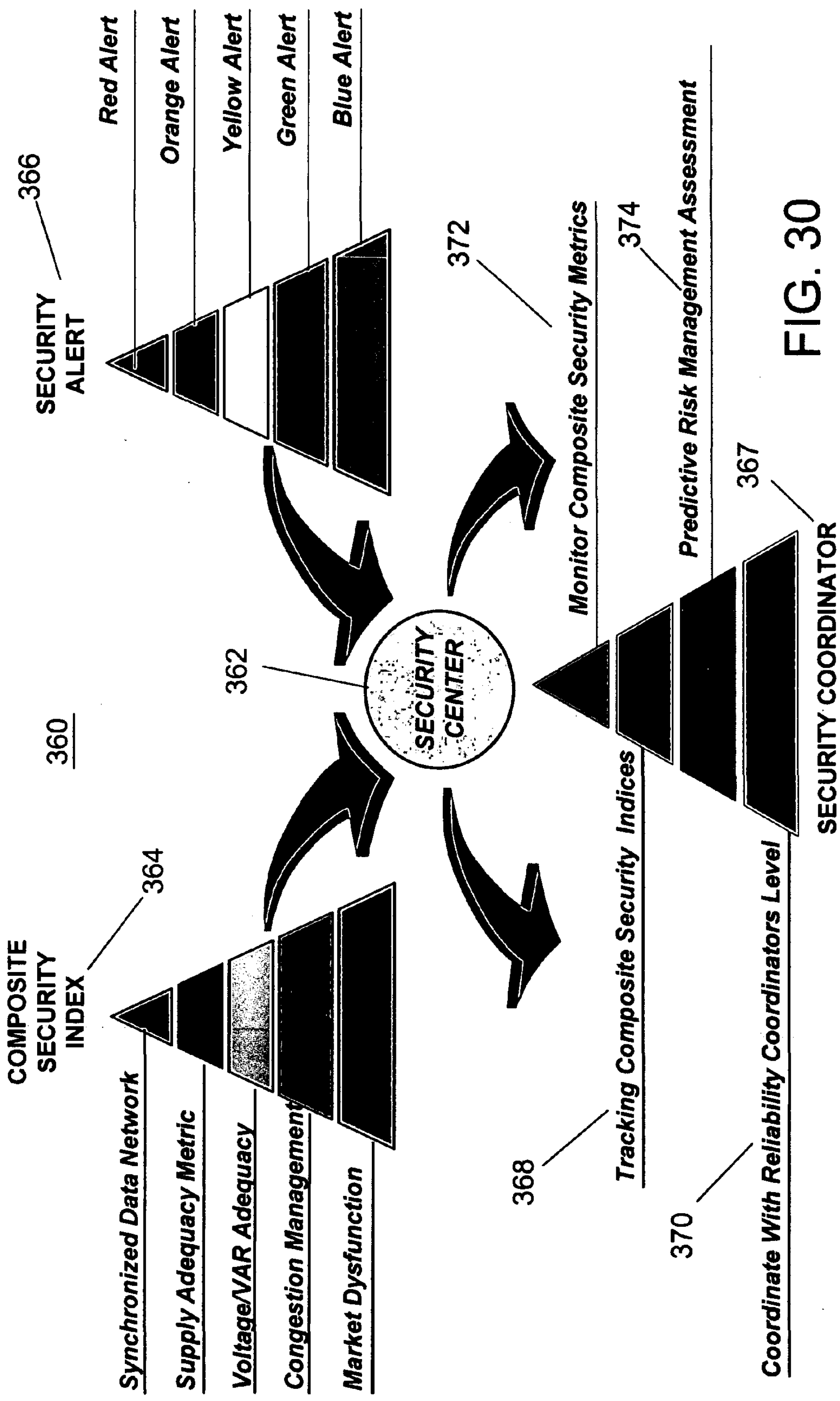

360
COMPOSITE SECURITY INDEX
364
Synchronized Data Network
Supply Adequacy Metric
Voltage/VAR Adequacy
Congestion Management
Market Dysfunction
SECURITY ALERT
366
Red Alert
Orange Alert
Yellow Alert
Green Alert
Blue Alert
362
SECURITY CENTER
372
Monitor Composite Security Metrics
374
Predictive Risk Management Assessment
367
SECURITY COORDINATOR
368
Tracking Composite Security Indices
370
Coordinate With Reliability Coordinators Level

FIG. 30

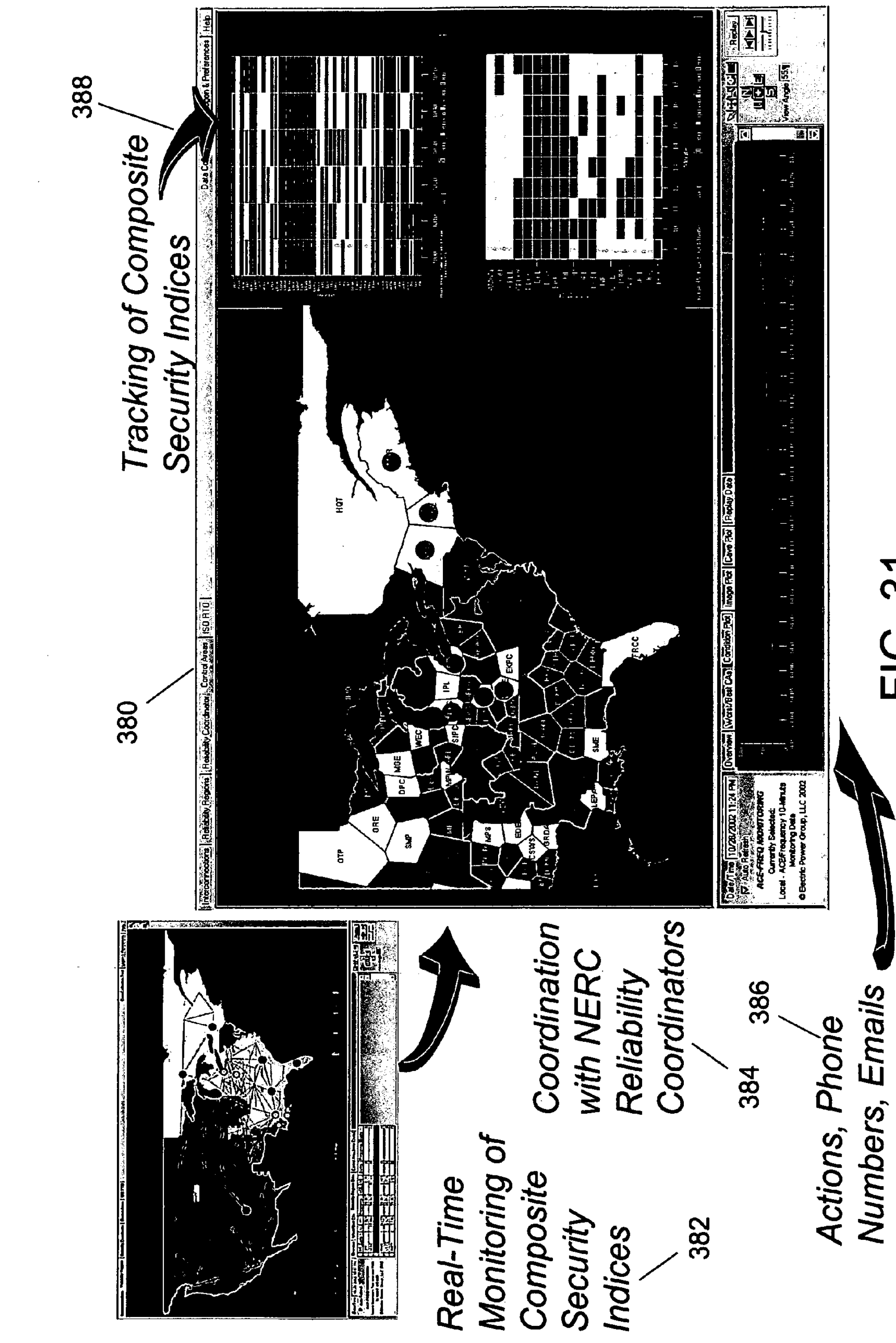

388
Tracking of Composite Security Indices
380
Real-Time Monitoring of Composite Security Indices
382
Coordination with NERC Reliability Coordinators
384
386
Actions, Phone Numbers, Emails

FIG. 31

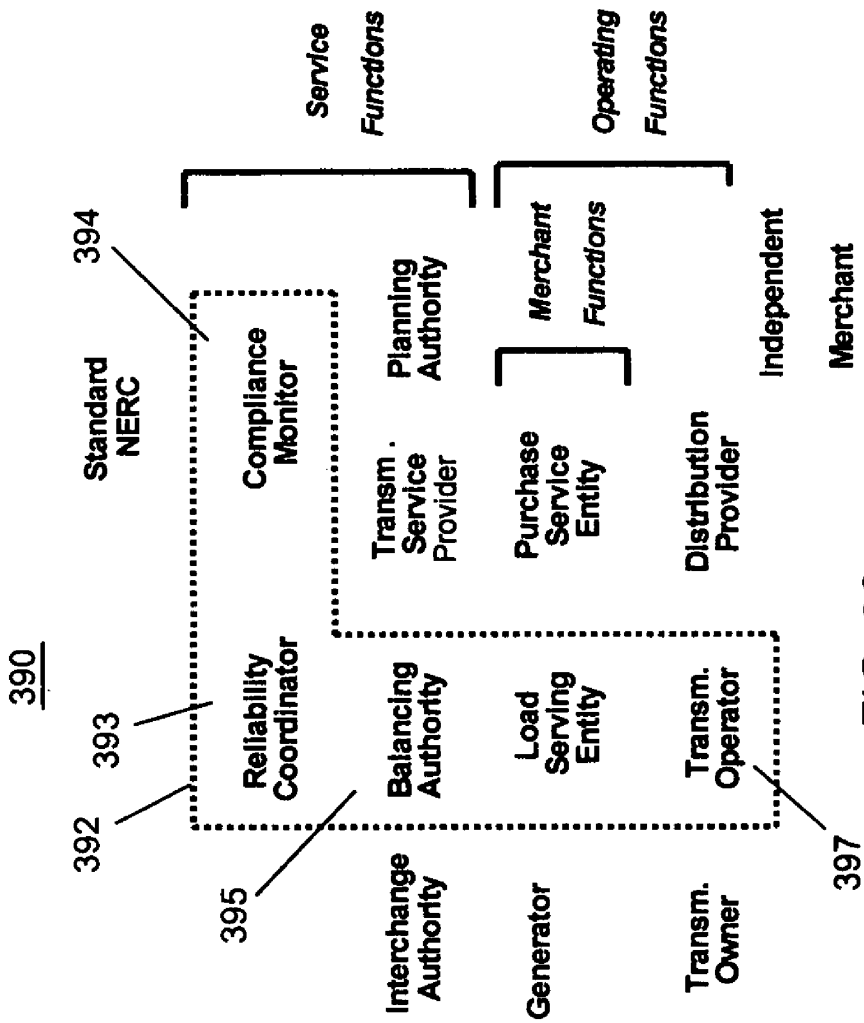

390
392
393
394
395
397
Standard NERC
Reliability Coordinator
Compliance Monitor
Interchange Authority
Balancing Authority
Transm. Service Provider
Planning Authority
Generator
Load Serving Entity
Purchase Service Entity
Merchant Functions
Transm. Owner
Transm. Operator
Distribution Provider
Independent Merchant
Service Functions
Operating Functions

FIG. 32

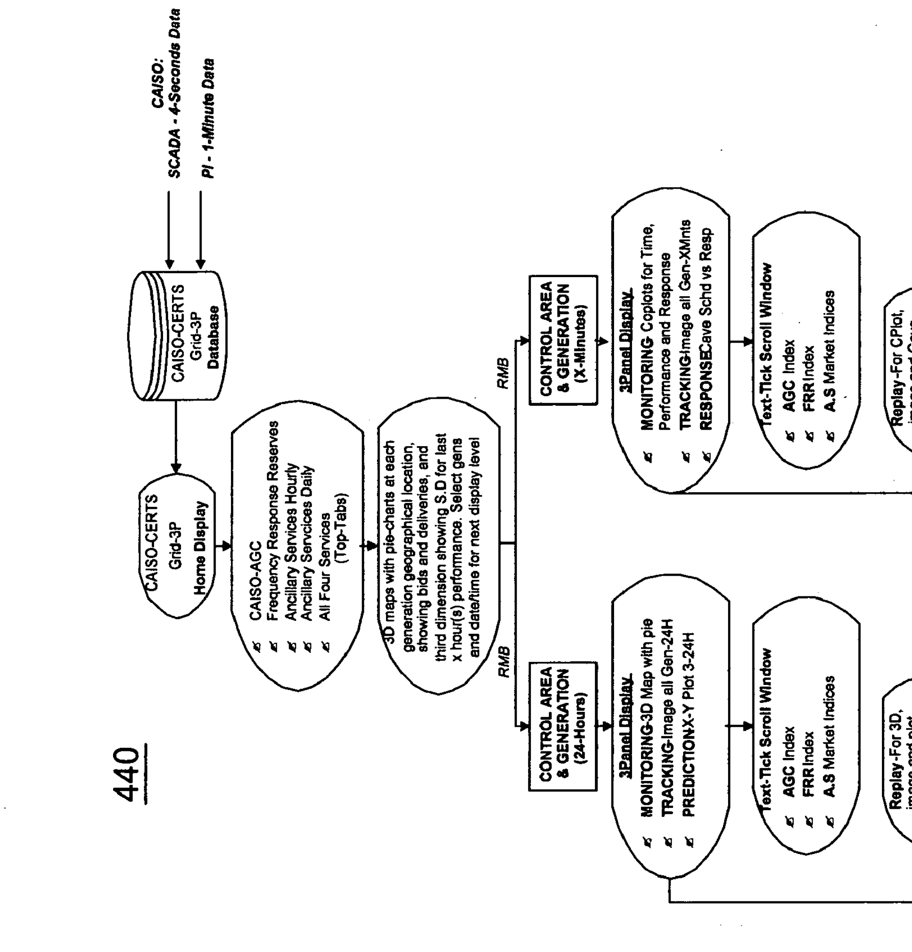

440
CAISO:
SCADA - 4-Seconds Data
PI - 1-Minute Data
CAISO-CERTS
Grid-3P
Database
CAISO-CERTS
Grid-3P
Home Display
CAISO-AGC
Frequency Response Reserves
Ancillary Services Hourly
Ancillary Services Daily
All Four Services
(Top-Tabs)
3D maps with pie-charts at each generation geographical location, showing bids and deliveries, and third dimension showing S.D for last x hour(s) performance. Select gens and date/time for next display level
RMB
RMB
CONTROL AREA
& GENERATION
(24-Hours)
CONTROL AREA
& GENERATION
(X-Minutes)
3Panel Display
MONITORING-3D Map with pie
TRACKING-Image all Gen-24H
PREDICTION-X-Y Plot 3-24H
3Panel Display
MONITORING-Cplots for Time, Performance and Response
TRACKING-Image all Gen-XMnts
RESPONSE-Cave Schd vs Resp
Text-Tick Scroll Window
AGC Index
FRR Index
A.S Market Indices
Text-Tick Scroll Window
AGC Index
FRR Index
A.S Market Indices
Replay-For 3D, image and plot. Default 3D. One Week Hourly
Replay-For CPlot, image and Cave. Default Image. 3-Hours By Minute

FIG. 33

450

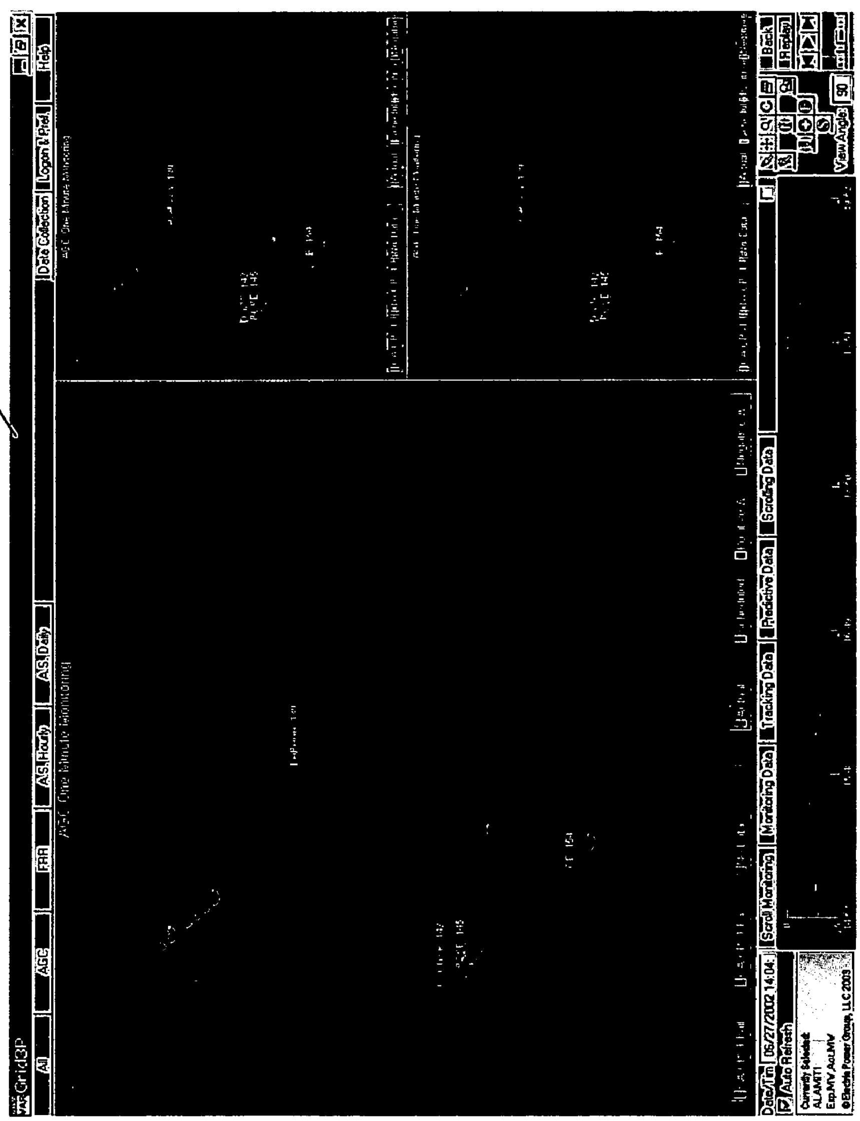


FIG. 34

460

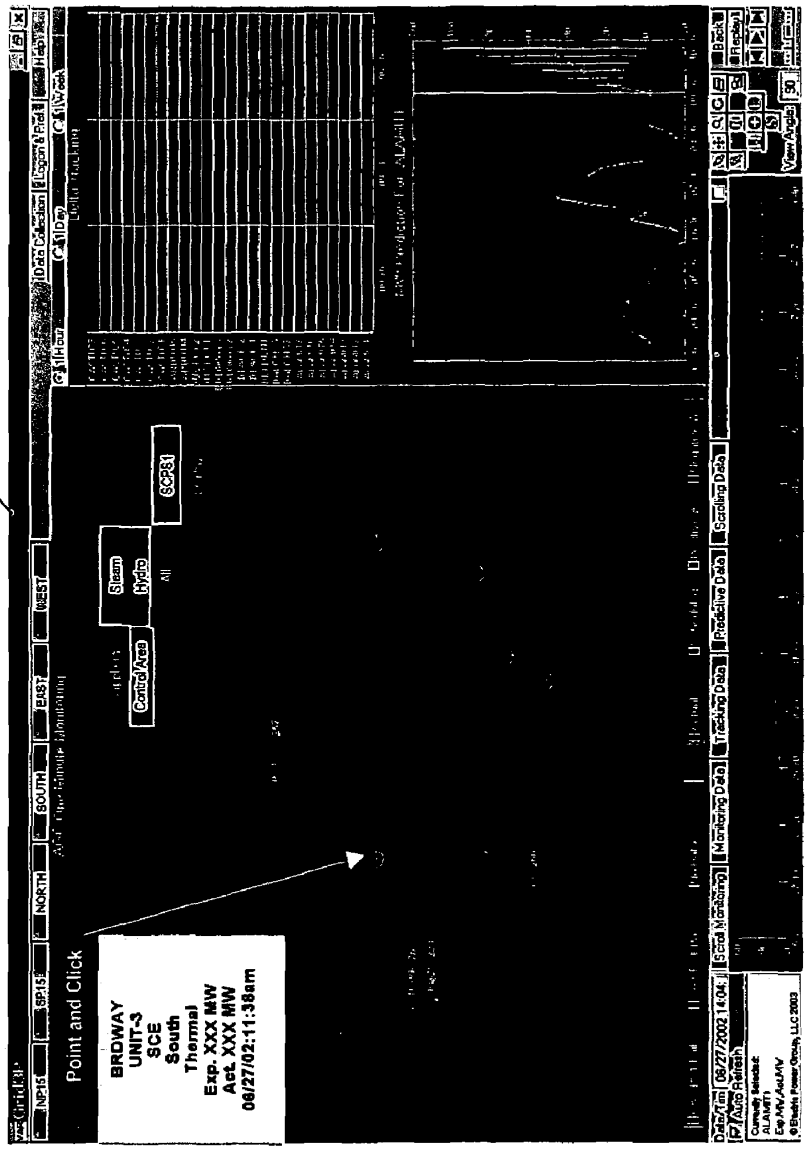
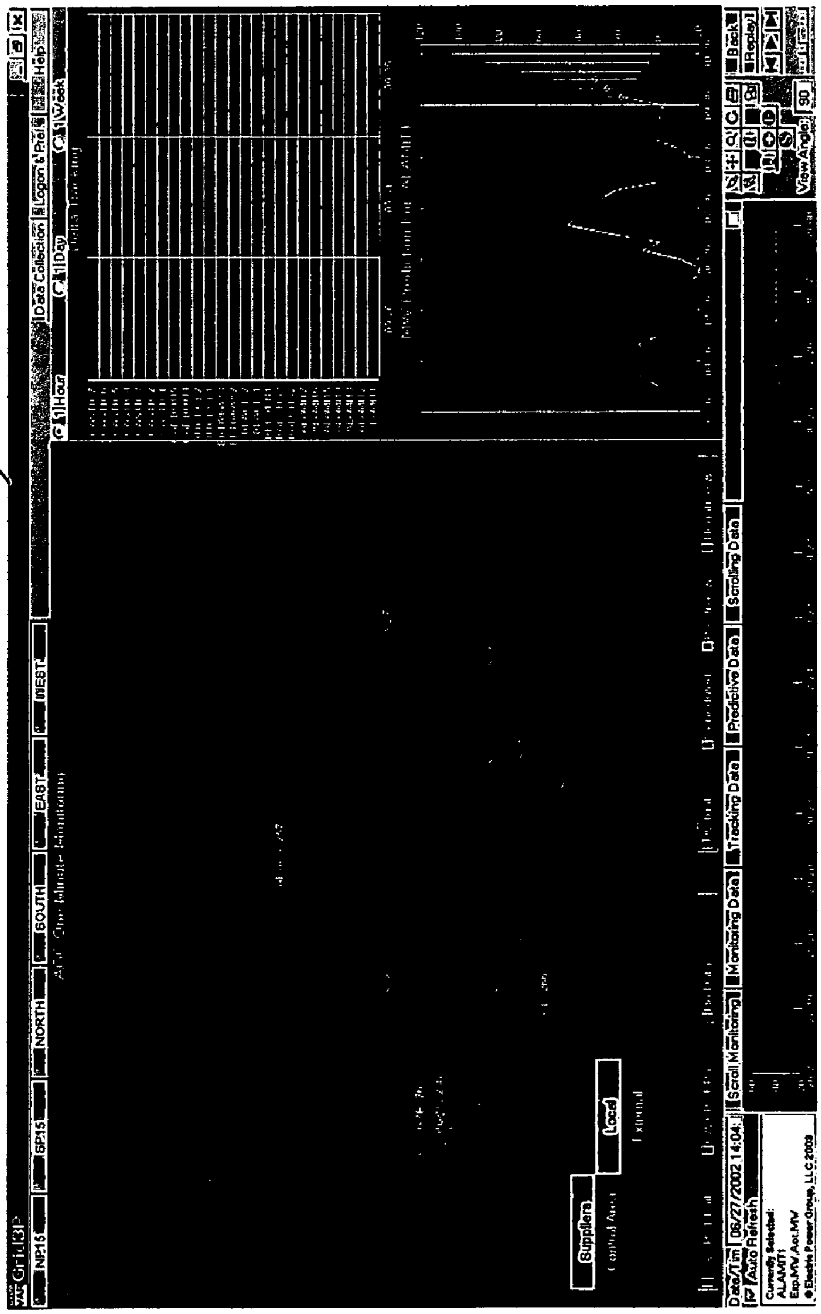

NP15
SP15
NORTH
SOUTH
EAST
WEST
Data Collection
Help
Steam
Hydro
All
Control Area
Point and Click
BRDWAY
UNIT-3
SCE
South
Thermal
Exp. XXX MW
Act. XXX MW
06/27/02:11:38am
Monitoring Data
Tracking Data
Predictive Data
Scrolling Data
Auto Refresh
Back
Replay
View Angle
30

FIG. 35

470



NP15
SP15
NORTH
SOUTH
EAST
WEST
Data Collection
Help
Suppliers
Load
Auto Refresh
Scroll Monitoring
Monitoring Data
Tracking Data
Predictive Data
Scrolling Data
Back
Replay
View Angle:

FIG. 36

480

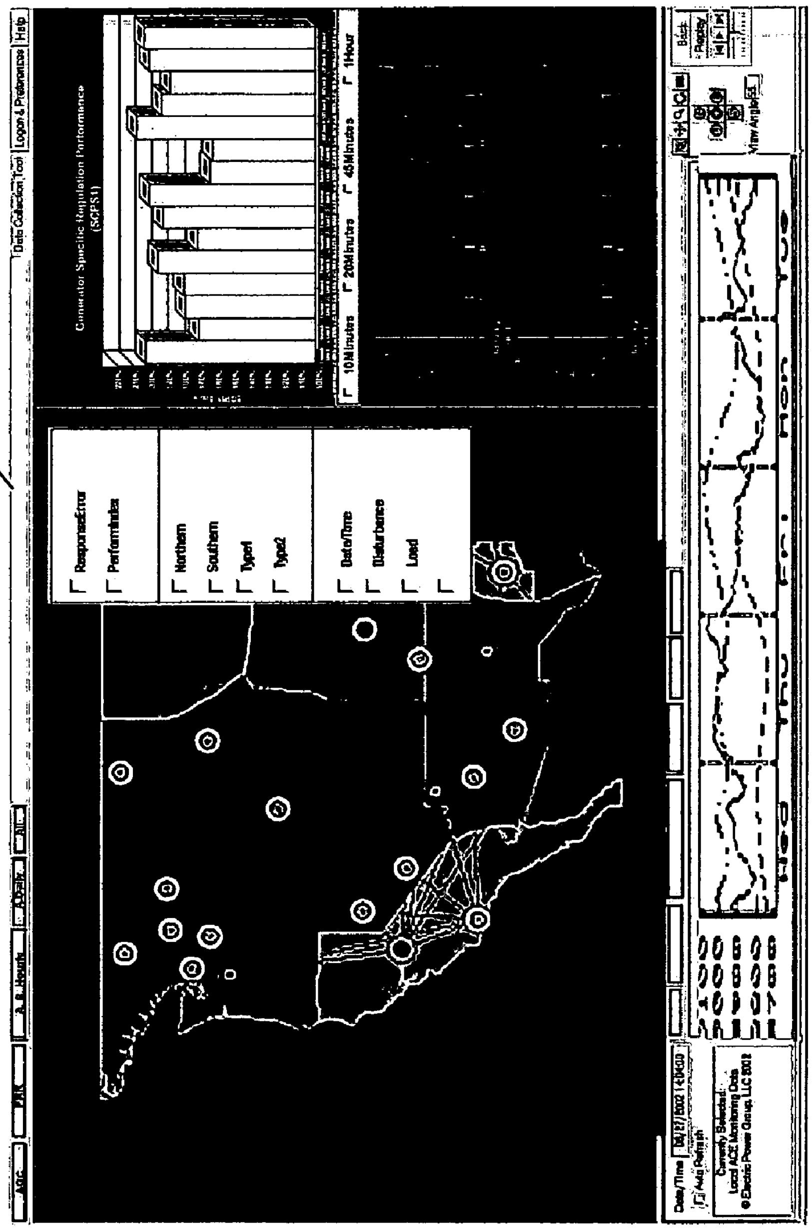


FIG. 37

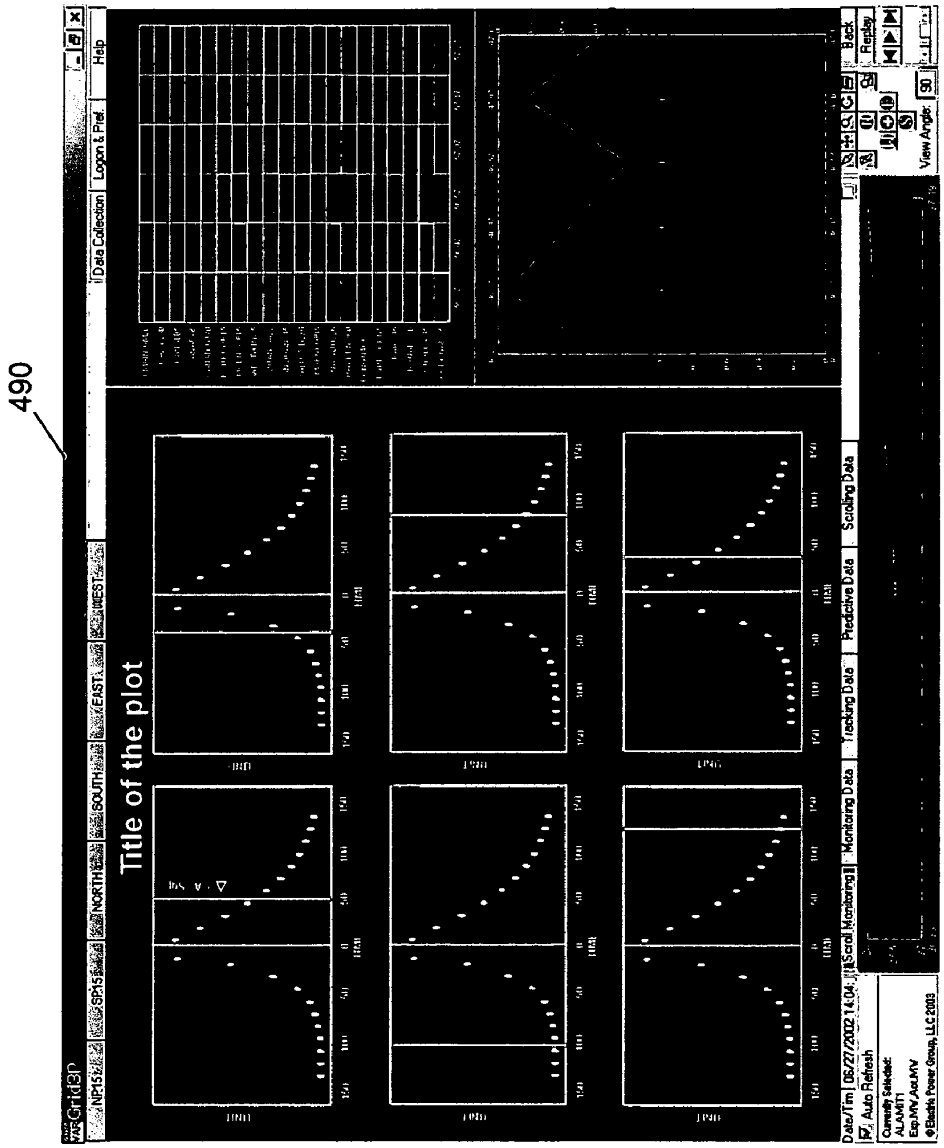

490
Title of the plot
Data Collection
Logon & Pref.
Help
Monitoring Data
Tracking Data
Predictive Data
Scrolling Data
Auto Refresh
Back
Replay
View Angle:

FIG. 38

REAL-TIME PERFORMANCE MONITORING AND MANAGEMENT SYSTEM

CROSS-REFERENCE TO RELATED APPLICATION(S)

This application claims priority to and the benefit of U.S. Provisional Patent Application No. 60/493,526 filed Aug. 8, 2003 and U.S. Provisional Patent Application No. 60/527,099 filed Dec. 3, 2003, the entire contents of both of which are incorporated herein by reference.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

This invention was made partially with government support under Department of Energy Contract # DE-AC03-76SF00098, Subcontract # 6508899. The Government has certain rights in this invention.

FIELD OF THE INVENTION

The present invention relates generally to a monitoring and management platform, and more particularly to a real-time performance monitoring and prediction system that has wide applicability to various industries and processes.

BACKGROUND

In various industries, the ability to monitor, track, predict and/or act in real-time is desirable. These industries include electric power, gas pipeline, water systems, transportation, chemicals and processes, infrastructure protection, security monitoring and others.

By way of example, in the electric power industry, power is typically supplied to customers in a four stage process of generation, transmission, distribution and end use. FIG. **1**A illustrates a typical process of generation, transmission and distribution of electricity. As illustrated in FIG. **1**A, the electricity is generated competitively by a number of power plants. The electricity is then transmitted through a number of transmission lines that are regulated by the Federal Energy Regulatory Commission (FERC). These transmission lines, which may be located in different states, are typically owned by the utility or transmission companies, and controlled by regional Independent System Operators (ISOs), Regional Transmission Organizations (RTOs) or utility companies that may be private or public. The generation and transmission of electricity are usually managed by regional entities that monitor the grid operations, market operations, security and other aspects of the electric power system.

The transmitted electricity is typically distributed through state or locally regulated distribution companies. The transmission and distribution systems utilize a number of devices for management and control of the electric system, including dynamic voltage support, remedial action schemes, capacitors, storage and flow control devices. The electricity is distributed to the customers as the end users, or consumers of electricity. Some of the customers may also have micro-grids of their own. The demand placed by these customers also needs to be managed.

Due to the enormous task at hand, there are a number of organizations responsible for overseeing these power generation, transmission and distribution activities. For example, there are over 3,000 utilities, thousands of generators, 22 Reliability Coordinators, and 153 Control Areas

(CAs) in the United States for monitoring and control of generation, transmission and distribution of electricity. While all these different entities at various different levels are involved in generation, transmission and distribution of electricity as well as monitoring and control in a power grid, there is no single integrated system that can be used to monitor and manage the electric power grid in real-time across all of the different elements of the power system. For example, there is no information management system for the power grid, which is integrated across multiple business systems, companies and Control Areas to manage the security, timeliness, accuracy or accessibility of information for grid operations, reliability, market operations and system security. Analogous issues may be apparent in other industries.

SUMMARY

In an exemplary embodiment according to the present invention, a real-time performance monitoring, management and prediction platform is provided. Systems based on the platform may be used to manage processes in various industries, based on current monitoring tools as well as tools that are under development, for example, in smart, switchable networks. Systems based on the platform preferably include visualization features that enable managers and operators in various industries to: measure key system operating and market metrics; monitor and graphically represent system performance, including proximity to potential system faults; track, identify and save data on abnormal operating patterns; and predict system response in near real-time by means of simulations and predictive analysis.

In one exemplary application of the present invention, a power grid monitoring and management system is provided. The power grid monitoring and management system includes a technology platform for real-time performance monitoring application for the electric power grid. The power grid monitoring and management system in one exemplary embodiment may also be referred to as a Grid Real-Time Performance Monitoring and Prediction Platform (Grip-3P™). The Grid-3P platform is designed to enable monitoring of a range of electric grid parameters, including metrics for reliability, markets, generation, transmission, operation, and security. The visualization features enable display of information geographically and graphically; in real time; and enables operators to define display levels—local or wide area, control area, interconnection or other user defined manner. This technology is being used to develop and implement real-time performance monitoring applications at Reliability Coordinator and Independent System Operator (ISO) locations, including the following applications: Area Control Error (ACE)-Frequency Real-Time Monitoring System; Control Area and Supplier's Performance for Automatic Generation Control and Frequency Response Services System; VAR-Voltage Management and Monitoring System; and Monitoring Applications based on Synchronized Phasor Measurements.

Examples of electric grid system components and metrics that could be monitored include electric interconnections, generators, voltage levels, frequency, market prices, congestion, market power metrics, demand forecasts, and other system components and metrics.

Another feature of the Grid-3P platform is the concept of multi-panel displays that allow: real-time monitoring of key metrics; display of history and performance tracking of key metrics; performing sensitivity evaluations and assessments of key metrics under alternative scenarios, and developing

predictions or near term forecasts of performance; and initiating actions, such as providing e-mail notification for alerting operators about abnormal conditions and the need to take action.

The power grid monitoring and management system may operate in a web environment, client-server, dedicated server, and/or secure proprietary network. In addition, the power grid monitoring and management system may allow interactive historical data collection and to present the collected data in tabular and/or specialized data-visuals. Further, the power grid monitoring and management system may be used to create interactive data reports from grid performance historical data saved in data-servers.

In an exemplary embodiment according to the present invention, a real-time performance monitoring system monitors an electric power grid having a plurality of grid portions, each said grid portion corresponding to one of a plurality of control areas. A monitor computer monitors at least one of reliability metrics, generation metrics, transmission metrics, suppliers metrics, grid infrastructure security metrics, and markets metrics for the electric power grid. A database stores the metrics being monitored by the monitor computer, and at least one display computer has a monitor for displaying a visualization of the metrics being monitored by the monitor computer. Said at least one display computer in one said control area enables an operator to monitor a said grid portion corresponding to a different said control area.

In another exemplary embodiment according to the present invention, a method of monitoring a performance of an electric power grid in substantially real-time is provided. The electric power grid has a plurality of grid portions, each said grid portion corresponding to one of a plurality of control areas. A monitor computer is used to monitor at least one of reliability metrics, generation metrics, transmission metrics, suppliers metrics, grid infrastructure security metrics, and markets metrics for the electric power grid. The metrics being monitored by the monitor computer is stored in a database, and a visualization of the metrics being monitored by the monitor computer is displayed on a monitor of at least one display computer. Said at least one display computer in one said control area enables an operator to monitor a said grid portion corresponding to a different said control area.

These and other aspects of the invention will be more readily comprehended in view of the discussion herein and accompanying drawings, in which like reference numerals designate like elements.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A illustrates a typical process of generation, transmission and distribution of electricity;

FIG. **1**B illustrates a process of generation, transmission and distribution of electricity, and a set of exemplary information management requirements according to the present invention;

FIG. **2**A is a block diagram that illustrates an exemplary performance management strategy according to the present invention;

FIG. **2**B illustrates a process of controlling generation, transmission and distribution of electricity with an integration of real time wide area monitoring for reliability management;

FIG. **2**C illustrates an infrastructure for a wide area reliability monitoring center (WARMC) of FIG. **2**B;

FIG. **3** is a block diagram that illustrates an exemplary performance management process according to the present invention;

FIG. **4** is a block diagram that illustrates an exemplary multi-layered platform for performance monitoring and management according to the present invention;

FIG. **5** is a block diagram that illustrates the integration into power generation, transmission and distribution of the power grid monitoring and management system in an exemplary embodiment according to the present invention;

FIG. **6** illustrates a power grid monitoring and management system of FIG. **5** and includes the major reliability applications for real-time reliability monitoring for NERC Reliability Coordinators and Control Area Dispatchers;

FIG. **7** illustrates an application of the power grid monitoring and management system for utilization by RTOs to monitor markets, operations, security, and other functions;

FIG. **8** illustrates an application of the power grid monitoring and management system in an exemplary embodiment according to the present invention;

FIG. **9** is a local area network (LAN) based hardware and software architecture for the power grid monitoring and management system in an exemplary embodiment according to the present invention;

FIG. **10** is a web-based hardware and software architecture for the power grid monitoring and management system in another exemplary embodiment according to the present invention;

FIG. **11** illustrates the architecture of an ACE-Frequency real-time monitoring application using the power grid monitoring and management system in an exemplary embodiment according to the present invention;

FIG. **12** illustrates five major functional components of the NERC ACE-Frequency real-time monitoring system in an exemplary embodiment according to the present invention;

FIG. **13** illustrates reliability functional levels and visualization hierarchy in an exemplary embodiment according to the present invention;

FIG. **14** illustrates an integrated visualization model in an exemplary embodiment according to the present invention;

FIG. **15** illustrates an ACE-Frequency real-time monitoring architecture of the power grid monitoring and management system in an exemplary embodiment according to the present invention;

FIG. **16** is a screen shot that illustrates a multiple view architecture of a display of the power grid monitoring and management system in an exemplary embodiment according to the present invention;

FIG. **17** is screen shot of a Cave diagram that represents a Frequency/ACE diagram in an exemplary embodiment according to the present invention;

FIG. **18** is a screen shot of a default display for a Reliability Authority in an exemplary embodiment according to the present invention;

FIG. **19** is a screen shot of an Interconnect-Epsilon map in a three-panel display in an exemplary embodiment according to the present invention;

FIG. **20** is a screen shot of a local view for a Control Area map in an exemplary embodiment according to the present invention;

FIG. **21** is a screen shot of a current Control Area map for a selected Control Area in an exemplary embodiment according to the present invention;

FIG. **22** is screen shot of a CPS map in an exemplary embodiment according to the present invention;

FIG. **23** is a screen shot of a three-panel view in an exemplary embodiment according to the present invention;

FIG. **24** is a screen shot of a data collection tool in an exemplary embodiment according to the present invention;

FIG. **25** is a screen shot of charts generated using the data collected using the data collection tool of FIG. **24**.

FIG. **26** illustrates utilization of NERC ACE-Frequency monitoring in an exemplary embodiment according to the present invention;

FIG. **27** illustrates a screen shot of a supplier-Control Area performance for AGC and frequency response application in an exemplary embodiment according to the present invention;

FIG. **28** illustrates a market monitoring system in the power grid monitoring and management system in an exemplary embodiment according to the present invention;

FIG. **29** illustrates a screen shot of a market monitoring application in an exemplary embodiment according to the present invention;

FIG. **30** illustrates a security center monitoring system in an exemplary embodiment according to the present invention;

FIG. **31** illustrates a screen shot of a real-time security monitoring application of the power grid monitoring and management system in an exemplary embodiment according to the present invention;

FIG. **32** is a block diagram of a NERC reliability functional model in an exemplary embodiment according to the present invention;

FIG. **33** illustrates a Control Area and suppliers performance monitoring and prediction platform for AGC, FRR and regulation A.S. in an exemplary embodiment according to the present invention;

FIG. **34** is a screen shot of a panel view for control area and suppliers performance for, AGC, FRR and A.S. in an exemplary embodiment according to the present invention;

FIG. **35** is a screen shot of a panel view for Control Area and generator response to AGC in an exemplary embodiment according to the present invention;

FIG. **36** is a screen shot for a panel view for Control Area and generators response to frequency response in an exemplary embodiment according to the present invention;

FIG. **37** is a screen shot for a panel view for Control Area and generators response to regulation A.S. in an exemplary embodiment according to the present invention; and

FIG. **38** is a screen shot of a common view for performance of AGC, FRR and X-minutes ancillary services regulation (default 10 minutes) in an exemplary embodiment according to the present invention.

DETAILED DESCRIPTION

Referring to FIG. **1**B, a set of exemplary information management requirements for the present invention may include: integration across multiple business system, companies and CAs; and information security, timeliness, accuracy, and accessibility.

Referring to FIG. **2**A, an exemplary performance management strategy according to the present invention contemplates identification of key metrics **1**, monitoring **2**, analysis **3** and assessment **4**. Utilizing the platform and system described herein, the strategy may be beneficially employed for a wide variety of industries and processes, including without limitation, electric power, gas pipeline, water systems, transportation, chemicals and processes, infrastructure protection, security monitoring and others.

According to an exemplary embodiment of the present invention, a wide area reliability monitoring center (WARMC) provides a visibility to system conditions across control area boundaries, improves reliability management capability, and/or prevents future blackouts. The WARMC provides Reliability Coordinator and Control Area operators with a wide area perspective of grid operations real-time, beyond its immediate area of responsibility. The WARMC may additionally have other functions and applications including new functions and applications to be developed, and may serve as a center that supports grid reliability for an entire Interconnection (e.g., Eastern Interconnection (EI)), for example.

In recent years, the functional disaggregation of electric utilities has resulted in gaps in the overall grid reliability management in terms of who (Control Areas, Reliability Coordinators, ISO/RTOs) has visibility of key system parameters with apparently no one having the full picture. By way of example, blackouts, such as the Aug. 14, 2003 blackout in the United States and Canada, may have been caused by a lack of situational awareness caused by inadequate reliability tools and backup capabilities. Further, deficiencies in control area and reliability coordinator capabilities to perform assigned reliability functions may also have led to blackouts.

During the blackouts, the operators may have been unaware of the vulnerability of the system to the next contingency. The reasons for this may include one or more of inaccurate modeling for simulation, no visibility of the loss of key transmission elements, no operator monitoring of stability measures (e.g., reactive reserve margin, power transfer angle), and no reassessment of system conditions following the loss of an element and readjustment of safe limits. The wide area real time monitoring for reliability management of the present invention is adapted to the changing industry structure and helps to reduce or prevent blackouts.

The wide area reliability monitoring functions of the present invention may be integrated with existing operations and provide system operators and Reliability Coordinators with tools for monitoring not only their own Control Areas but also adjacent Control Areas and the Interconnection. The integration of the real time wide area monitoring for reliability management with existing control, communications, and monitoring infrastructure is shown in FIG. **2**B, for example.

As shown in FIG. **2**B, operators currently have access to databases or platforms and perform control and monitoring functions at three levels: 1) Level **1**-local power plant controls using plant data to control local generation of power; 2) Level **2**-SCADA (regional control center) using generation, transmission and substations data to control regional and local substations, which involves controlling local load-generation balance-AGC and local grid switching in real-time; and 3) Level **3**-EMS for Control Area operations including use of state estimation, grid security analysis and security constrained dispatch, using grid voltage and interconnection frequency-ACE data.

The WARMC according to an exemplary embodiment of the present invention introduces a new Level **4**, which utilizes existing SCADA data as well as time synchronized data from phasors or other sources and/or other new data sources for wide area monitoring. As shown in FIG. **2**B, the WARMC provides one or more of the following applications: 1) Wide-Area Load-Generation Balance-ACE-Frequency real-time monitoring; 2) Wide-Area Grid Dynamics and Reliability monitoring-RTDMS; 3) real time operations

management information; and 4) state estimation using phasors. The WARMC may have one or more of other monitoring, management information reporting, state estimation, and controls applications.

The WARMC provides a wide area monitoring and reliability management capability that extends across control area boundaries. The WARMC may include one or more of monitoring applications, connectivity with other Interconnection entities, improved phasor and PDC hardware, and secure and redundant communication networks for data exchange. The WARMC may enable RTOs, Independent Transmission Owners (TOs), North American Electrical Reliability Council (NERC), other Interconnection stake holders, and/or the like to monitor key reliability metrics impacting their respective areas and provide the capability to monitor and manage an entire Interconnection grid (e.g., Eastern Interconnection grid).

By way of example, the WARMC may provide one or more of the following functions or capabilities: 1) wide area system visibility; 2) data connectivity to key RTOs and reliability management organizations; 3) time synchronized data in real time; 4) monitoring of key grid reliability metrics for an Interconnection (e.g., Eastern Interconnection); 5) real time performance monitoring and reporting; 6) enhanced state estimation; 7) fast simulation and modeling; and 7) smart grid with automated controls.

The WARMC may be fully automated, such that it will compile critical high speed data, process it, provide Interconnection (e.g., EI) reliability authorities with reliability information on the health of the Interconnection and, as required, may enable/disable remedial actions schemes (RAS) and may re-configure the grid. The WARMC may be linked through secure, reliable and redundant communications to key RTOs, transmission owners, utilities, and control area operators. The conceptual framework for an WARMC infrastructure is shown in FIG. **2**C. As can be seen in FIG. **2**C, the WARMC **2'** is coupled via a wide area network to a number of RTOs **1**-*n,* one or more super computers and a number of TOs **1**-*n.*

The WARMC should have access to critical real-time and historical operating data from all regions of an Interconnection (e.g., EI) to perform one or more of real time monitoring, post disturbance assessments, analyses for future enhancements and modeling to support a smart grid with automatic controls.

By way of example, the WARMC may have the necessary infrastructure, support systems and data to provide meaningful information for TOs, RTOs, and Reliability Coordinators to effectively perform one or more of the following: 1) validate the next-days operating plan and ensure the bulk power system can be operated reliably in anticipated normal and contingency conditions; 2) perform wide area monitoring, tracking and management of real-time grid operations; 3) anticipate and respond to changing conditions and flows; and 4) simulate "what if" scenarios.

The WARMC may also have capabilities to perform post disturbance assessment functions including one or more of: 1) evaluating compliance with NERC/Reliability Regional Standards; 2) Providing feedback to the pre-planning (day-ahead) process; 3) and validating model representation of expected grid performance. The WARMC may also define enhancements to the grid by, for example, assessing constraints, bottlenecks and vulnerabilities that will have a negative impact on grid reliability.

Referring now to FIG. **3**, the identification and use of key metrics **1** involves the evaluation and development of standards that may be quantified and measured. Metrics exist for a particular industry and different areas of a particular industry. For example, there may be metrics relating to reliability and others relating to markets, in which the metrics for each subcategory may overlap. Monitoring **2** contemplates the use of tools, whether they exist now or become available in the future, for tracking actual performance in real-time with a goal, among others, of looking for early warning signs. Analysis **3** contemplates converting archived monitoring information into meaningful information. Such data includes without limitation, risk analysis, grid data, depending on the particular industry or process being monitored, market data, historical data, and key reliability indicators. Assessment **4** contemplates the determination of impacts on reliability, markets, efficiency and asset utilization. Examples, which may change depending on the particular industry or process being assessed, include risk assessment, grid reliability and market efficiency. The desired assessment may modify the parameters or metrics that are monitored to achieve the desired results.

In one exemplary application of the present invention, the Grid-3P system, based upon a real-time performance and prediction platform for power grid monitoring and management, includes monitoring of generation/demand, grid data and markets as more particularly set forth herein. By way of example, the WARMC discussed above may be based on the Grid-3P system.

The reliability applications may include one or more of real-time monitoring of voltage/volt-ampere reactive (VAR), Area Control Error (ACE)/Frequency, Area Interchange Error (AIE)/Schedules, and/or other grid attributes and performance metrics. The generation applications may include suppliers and Control Area responses to Automatic Generation Control (AGC), frequency response and ancillary services, ramping response, and/or other metrics. The grid infrastructure security application may include one or more of system vulnerability, exposure (in terms of population, cities, etc.) and/or other metrics. Market applications may include one or more of generation market power, price spikes and/or other metrics.

In another exemplary embodiment according to the present invention, the power grid monitoring and management system enables one or more of real-time monitoring, historical tracking, prediction (near real-time forecasting up to 6-hours or what if sensitivity analysis), and actions (notification, system re-dispatch, mitigation measures, etc.) In other embodiments, the forecasting may be performed for more than six (6) hours.

In still another exemplary embodiment according to the present invention, the power grid monitoring and management system provides displays that utilize data and information that are user-defined and may or may not be algorithmically correlated with other displays.

In a further exemplary embodiment according to the present invention, data monitoring may be in real-time or near real-time for monitoring purposes. For example, real-time may be 1-4 seconds snapshot or up to 5 to 10 minute snap shots.

In yet further exemplary embodiment according to the present invention, the power grid monitoring and management system may be utilized to create a standalone monitoring system or be integrated with Security Control and Data Acquisition (SCADA), Energy Management System (EMS), PMUs-PDCs (phasor measurement units-phasor data concentrators) or other control power systems. The SCADA is a system of remote control and telemetry used to monitor and control transmission systems. In other words, the power grid monitoring and management system utilizes

data from or is integrated with at least one of SCADA, EMS, PMUs-PDCs and another control power system.

In a still further exemplary embodiment according to the present invention, the power grid monitoring and management system may be used with standard monitoring and control applications and/or end-user defined customer applications.

Referring to FIG. **4**, the platform incorporates a multi-layered approach to performance monitoring and management. Layer **1** (**5**), the data layer, incorporates conventional relational databases with time series capability (for real-time monitoring and synchronization), a data archival system and/or information management with data mining capabilities. Further, layer **1** includes web-based data communications, COM+ databases and data conversion APIs. One purpose of Layer **1** is to read data from conventional databases that gather the data in real-time, and to communicate the data in real-time.

Layer **2** (**6**), which uses analytical algorithms for massaging the data accumulated in the databases of layer **1**, includes two sublayers (**6***a* and **6***b*), one focusing on optimization, forecasting, statistics and probabilistic technologies, and other on real-time performance monitoring. Within layer **2***a* (**6***a*), the platform includes tools and algorithms for linear and non-linear optimizing, self-organize maps and generic algorithms, forecasting, probabilistic analysis and risk assessment, multivariate statistical assessment, performance metrics definition and assessment, and other analytical technologies that may become available. Within layer **2***b* (**6***b*), the system includes real-time ACE-frequency monitoring, real-time suppliers control area performance for AGC and FR, voltage VAR management, dynamics monitoring using phasor measurements and other applications that may become available.

Dynamic monitoring using phasor analysis is particularly important in systems where monitoring data at subtransient levels may be useful. By way of example, existing power systems have dynamic behavior on the order of milliseconds. Traditional sampling, however, occurred at 4 second intervals. New monitoring techniques enable sampling up to 20-30 times per seconds or more. The present system, using dynamic phasor analysis, is capable of analyzing data gathered at subtransient intervals, synchronizing the data to other system parameters based on the time series capability of layer **1**, and presenting the data for visualization in an organized and logical manner in layer **3**.

Deployment of phasor technology over wide areas is useful for supporting reliable region-wide and inter-regional transfers of electricity without facing transient reliability conditions. An objective of real time dynamics performance monitoring using phasors is to provide grid operators with phasor data in real-time so that they can obtain a more accurate picture of the actual health of the grid. The information allows them to verify that they are operating within the transient boundaries of safe operation, as determined by off-line planning studies, as well as whether the operating guidelines provided by these studies remains valid. Such real-time data provided by phasor or other real time monitoring technologies also supports creation of an automatic, switchable grid that can sense and respond automatically to warning signs of grid emergencies.

Layer **3** (**7**) uses a novel visualization system that includes a multi-layer view for geo-graphic, wide and local areas. Such a system that allows local or wide area visualization provides significant benefits for understanding the effect of national or neighboring areas on local areas or interest, such as local utilities. In yet another exemplary embodiment

according to the present invention, the power grid monitoring and management system is flexible to include one or more dynamic geographic displays and several data or text panels in one or more windows for monitoring, tracking, prediction, and actions or mitigations. Further, by synchronizing data from various sources and presenting it as such, the system enables the user to visualize a wide array of phenomena that may have an impact at a given time on the area or process of interest. The system further provides auto-onelines for tracing the path of electricity, water or other resources through the system. These diagrams allow the user to visualize potential sources of faults or other aspects of the system that may lead to system faults, and to take appropriate action prior to such a fault.

In an exemplary application of the present invention, new methods, tools and technologies are provided to protect and enhance the reliability of the U.S. electric power system by providing a real-time performance monitoring platform. The power grid monitoring and management system of the present invention, for example, includes a platform for performing real-time monitoring of frequency of electricity, customer usage ("load") and/or the amount of power being generated ("generation"). What may also be monitored is the difference between load and generation, and its effect on the frequency of the system.

In the exemplary embodiment, the system includes a series of modular, but integrated, computer-based, real-time data-to-information engines and graphic-geographic visualization tools that have served as a platform to develop reliability applications to assist operating authorities, business entities or companies, e.g., Independent System Operators (ISOs), Regional Transmission Organizations (RTOs), Reliability Coordinators and Control Area Dispatchers in their management of grid reliability, which may use different business systems. For North American Electric Reliability Council (NERC), these applications include the ACE-Frequency and AIE real-time monitoring systems.

The ACE may be defined as an instantaneous difference between net actual and scheduled interchange (i.e., energy transfers that cross control area boundaries), taking into account the effects of frequency bias including a correction for meter error. An AIE survey may be used to determine the Control Areas' interchange error(s) due to equipment failures or improper scheduling operations or improper AGC performance, where AGC may refer to equipment that automatically adjusts a Control Area's generation from a central location to maintain its interchange schedule plus frequency bias. The ACE and AIE monitoring systems together may be referred to as a Compliance Monitoring System (CMS). The CMS may also include one or more other components.

The ACE-Frequency and AIE real-time monitoring system applications enable NERC Reliability Coordinators to monitor ACE-Frequency performance and compliance with performance operational guides within their jurisdictions, and also allow NERC staff and subcommittees to analyze and assess control data to improve reliability tracking and performance. The ACE-Frequency real-time monitoring system, for example, translates raw operational control data into meaningful operations performance information for end users. Should an abnormal interconnection frequency occur, a real-time interconnection abnormal frequency notification (AFN) may be automatically issued via e-mail and/or beepers describing the date, time and magnitude of the frequency abnormality to specific operational authorities, NERC Resource Subcommittee members and NERC Staff.

The notification recipients using the ACE-Frequency monitoring system functionality can quickly assess the abnormality's root cause by drilling down from wide-area to local-area visualization displays that include appropriate information and analysis graphs to easily identify and assess those Control Area(s) out of compliance and potential originators of the notified interconnection frequency abnormality. A Control Area may be defined as an electrical system bounded by interconnection (tie-line) metering and telemetry. The Control Area controls generation directly to maintain its interchange schedule with other Control Areas and contributes to frequency regulation of the Interconnection. Interconnection may refer to any one of the bulk electric system networks in North America: Eastern, Western and ERCOT, and may also refer to Quebec electric system network. When not capitalized, it may also refer to facilities that connect two systems or Control Areas.

FIG. **5** is a block diagram that illustrates the integration into power generation, transmission and distribution of the power grid monitoring and management system in an exemplary embodiment according to the present invention. The top part of FIG. **5** illustrates that the current business model is segmented into generation, transmission, distribution, markets and security. It can be seen here that the vertically integrated business model historically used by utilities has evolved to a segmented market dispersed among separate entities.

The power grid monitoring and management system has been developed to serve as the base for the development of reliability applications for real-time monitoring, tracking and prediction for the reliability performance of Control Areas, generation, grid, markets, and security. Control Area's ACE, interconnection's frequency and interchange data on top of the power grid monitoring and management system provide a common tool to be utilized by NERC Reliability Coordinators, Control Area Dispatchers, and Transmission Dispatchers. The bottom of FIG. **2** also shows that reliability applications developed using the power grid monitoring and management system may serve as complement for traditional SCADA/EMS systems and for the periodic reporting requested by NERC for post performance.

As can be seen in FIG. **5**, various different data are provided by generation **10**, utilities **20** (transmission **12** and substations **14**), market **16** and security **18**. These data, such as generation data, grid data, market data and performance data are provided to one or more various different organizations **22** such as, for example, ISOs, RTOs, transmission companies, Control Areas and the like.

One or more of these organizations perform real-time operations **24** such as scheduling, dispatching, system security, ancillary services and the like. Also, one or more of these organizations perform assessment and reporting **26** such as reports to reliability authorities such as ISOs, RTOs, FERC/PUCs and NERC.

As illustrated in FIG. **5**, the power grid monitoring and management system in the described exemplary embodiment provides an infrastructure for integrating the monitoring and control of real-time operations, assessment and reporting provided by various different entities using data provided by still other various different organizations.

FIG. **6**, for example, shows an expansion of the power grid monitoring and management system **28** from FIG. **2** and includes the major reliability applications for real-time reliability monitoring for NERC Reliability Coordinators and Control Area Dispatchers. The top part FIG. **3** shows the applications target for Reliability Coordinators, ACE-frequency, AIE and control performance standards (CPS). The bottom part of FIG. **6** shows the applications target to Control Area Dispatchers, performance compliance of Control Areas, suppliers to AGC, FRR and ancillary services markets.

As can be seen in box **30**, NERC Reliability Coordinators monitor several requirements, including ACE-Frequency, to maintain and enhance the reliability of their jurisdictions. The ACE-Frequency Monitoring System, shown in the upper applications box (Reliability Region Performance Monitoring Platform) **34**, provides applications for each Coordinator within each of their Reliability Regions. Reliability Coordinators utilize those applications to monitor performance and compliance within their Regions and notify the appropriate Control Area Dispatchers as abnormalities occur. Control Area Dispatchers pinpoint problem sources by monitoring the response performance of their Control Area and suppliers to AGC monitoring system, frequency response resources and ancillary services.

For example, in one exemplary embodiment, the power grid monitoring and management system may be described in reference to performance monitoring, tracking and short term prediction of California Independent System Operator (CAISO) Control Area and suppliers response to AGC, frequency response reserves (FRR) and ancillary services application as shown in box **36** (Control Area Performance Monitoring Platform) to support Control Area Dispatchers Monitoring Requirements (**32**). This application represents further progress towards grid reliability technologies and management tools that present real-time performance, tracking and predictive information across several spheres of grid operating and reliability concerns.

FIG. **7** illustrates an application of the power grid monitoring and management system **40** in an exemplary embodiment according to the present invention. The power grid monitoring and management system includes a platform to support RTO functions (**42**) such as markets, operations, security and reliability monitoring.

FIG. **8** illustrates functions of the power grid monitoring and management system **50** in an exemplary embodiment according to the present invention. The power grid monitoring and management system **50** includes a platform for performing one or more of real-time performance monitoring **52**, historical performance tracking **54**, sensitivities and short term prediction **56**, and action & simulations for reliability and markets **58**.

As part of the real-time performance monitoring **52**, the power grid monitoring and management system may monitor one or more of voltage/VAR, ACE-Frequency, transmission congestion, generator performance for AGC and frequency response and market prices/spikes.

For historical performance tracking **54**, the power grid monitoring and management system may track one or more of Interconnection, Generator, Region/Zone/Substation as well as market.

As part of sensitivities and short term prediction **56**, the power grid monitoring and management system may predict/handle one or more of system demand, generator response, voltage sensitivities, distance from collapse and short term predictions.

The actions and simulations **58** performed by the power grid monitoring and management system may include one or more of notifications, reserves & ancillary services, capacitor dispatch, generation re-dispatch, VAR management and automatic mitigation.

FIG. **9** is a local area network (LAN) **100** based hardware and software architecture for the power grid monitoring and management system in an exemplary embodiment according

to the present invention. The architecture includes a number of clients **114**, **124** that interface with a server **110** over the LAN **100**. The server and clients, for example, may be COM+ server and clients, and the communications may take place using XML language.

Each client **114**, **124** interfaces with the power grid monitoring and management system client **116** and **126**, respectively. The display of the power grid monitoring and management system **118** and **128** are used to provide visual indication of monitoring and tracking to the user.

The server **110** is coupled to a power grid monitoring and management system database **104**, for example, over an OLEDB connection. The server **110** is also connected to a power grid monitoring and management system application server **102** and a client **108**. The communication between the server **110** and the client **108**, for example, is performed using XML language. Further, the client **108** communicates with one or more monitoring applications **106** using the XML language. The one or more monitoring applications **106** also interface with the power grid monitoring and management system application server **102**. The monitoring applications are connected over OLEDB connection and/or other data base connections to customer proprietary databases or data platforms **112**. The customer proprietary database or data platform **112** may include one or more of SCADA (Supervisory Content and Data Acquisition) database, market database, PI database and Phasor Data database. The LAN-based architecture may have different configurations in other embodiments.

FIG. **10** is a web-based hardware and software architecture for the power grid monitoring and management system in another exemplary embodiment according to the present invention. On the power grid monitoring and management system application server side, the configuration is identical to that of the LAN-based hardware and software architecture. The server **110**, however, communicates with another client (which may be a COM+ client) **142** using the XML language. The client **142** is coupled with an Internet Information Server (IIS) **140**. A power grid monitoring and management system web server **144** also communicates with the client **142** and the IIS **140**. The IIS **140** communicates over the Internet **150** using XML language and Simple Object Application Protocol (SOAP) protocol with the visualization programs **152** and **156**, respectively, for visual communication with users on web clients **154** and **158**, respectively. The web-based architecture may also have different configurations in other embodiments.

For example, in both the architectures of FIGS. **9** and **10**, only two clients are shown on the client side. In practice, however, there may be more than two clients. Further, the power grid monitoring and management system application server **102** may be coupled to both the LAN-based clients and web-based clients over the LAN and the Internet, respectively. Further, the Internet may be replaced or complemented by an Intranet or any other similar proprietary or non-proprietary networks.

FIG. **11** illustrates the architecture of an ACE-Frequency real-time monitoring application **160** using the power grid monitoring and management system in an exemplary embodiment according to the present invention. The ACE-Frequency monitoring system receives ACE and frequency data from the nation's Control Areas (Data Collection **162**), calculates performance parameters (e.g., reliability compliance parameters **170**) for each reliability jurisdiction and compares those performance parameters to NERC reliability compliance guides (Standards & Algorithms **166**). The results of these comparisons are then displayed graphically and (Visualization **164**) on a geographical map (Geography **168**) for use by each of the Reliability Organization from each of the layers, depicted in the lower, right pyramid **172**. The tiers of the pyramid comprise the control areas, reliability coordinators, reliability transmission organizations, reliability regions, and Interconnections.

FIG. **12** illustrates five major functional components of the NERC ACE-Frequency real-time monitoring system **180** in an exemplary embodiment according to the present invention: Local Monitoring **182**, Global Monitoring **184**, Abnormal Frequency Notification (AFN) **186**, Interactive Data Collection (IDC) **188** and Unavailable Data Reporting (UDR) **190**. Following are description of each one of the major functional components.

The first is the Local Monitoring Geographic-Graphic Visualization **182**. In the described exemplary embodiment, most of the ACE-Frequency visualization is geographic-graphic oriented and covers different time windows from current time to 30-days. The local-visualization option covers from current time to 1-hour, and it offers to end users three different views of Control Area ACE and Interconnection frequency data displayable in the three-panel window visualization.

The second is the Global Monitoring Geographic-Graphic Visualization **184**. In the described exemplary embodiment, this option uses the Epsilon performance parameter as an indicator of the frequency performance for each of the interconnections. For example, it shows the performance parameter for two time windows, 6-hours and 30-days. It also uses a power grid monitoring and management system three-panel window visualization as will be described below.

The third is the AFN **186**. The real-time AFN is a real-time monitoring component of the ACE-Frequency Monitoring System. The AFN is designed for real-time monitoring of abnormal interconnection frequencies, and to automatically issue e-mails to specific NERC Resources Subcommittee members and NERC staff when predefined abnormal frequency performance criteria are met. E-mail recipients may, for example, use the ACE-Frequency monitoring system capabilities to assess root causes of the abnormal frequencies when notified. The input data to the AFN may be provided by Control Areas to NERC over a secure connection using NERCnet, XML, and/or SOAP technologies.

The fourth is the IDC function **188**. Via the IDC functionality, NERC subcommittees, NERC staff, and operating engineers can interactively define the historical window of time and the specific control-performance parameter they need to analyze and assess frequent disturbances. Once data is collected from the NERC data server, the users can use equivalent reliability coordinator visualization and/or save the data in comma-delimited files.

The fifth is the DRG function. The DRG offers the capability to interactively identify and report Control Area data transfer performance. Users can select hourly, daily, weekly, and/or monthly reports and select the specific data they want to assess for availability.

It has been demonstrated by Control Area Dispatchers that the more effective operational displays are those that follow a hierarchical approach to present operational data for current time and other key windows of time. The power grid monitoring and management system visualization model in an exemplary embodiment of the present invention encompasses displays at high and low levels to meet the varying needs of different reliability application users. Thus, in the described exemplary embodiment, monitoring applications

are developed for wide-area and local area users using the power grid monitoring and management system.

FIG. **13** illustrates reliability functional levels and visualization hierarchy in an exemplary embodiment according to the present invention, and FIG. **14** illustrates an integrated visualization model in an exemplary embodiment according to the present invention.

The hierarchal structure in FIG. **13** shows that it is desirable for the Reliability Coordinators to have a wide-area view of their jurisdictions for reliability compliance monitoring **192**. Also, it is desirable for the ISOs and RTOs to have the ability to assess performance and trends (**194**) of their Control Areas. In turn, it is desirable for Control Areas to have local area information **196** to pinpoint specific suppliers reliability performance issues. The ACE-Frequency tool allows Reliability Coordinators to monitor ACE-Frequency performance and compliance for each of their jurisdictions using wide-control-area graphic-geographic visualization.

For the definition and design of the ACE-Frequency graphic-geographic visuals for each of the visualization layers shown in FIG. **13**, the data collection **200**, computational and display (or visualization) models **202**, **204** from the power grid monitoring and management system shown in the first three vertical segments on FIG. **14** may be used. For the NERC ACE-Frequency real-time monitoring system, about **123** Control Areas transmit ACE and frequency data to a data server located at NERC (data collection).

The data is processed and performance parameters are calculated in the computational engines (computational model) of the power grid monitoring and management system. The design and deployment of each of the displays follows the three steps (i.e., human factors, user interaction and composition) illustrated in the display model section **204** on FIG. **14**.

FIG. **15** illustrates an ACE-frequency real-time monitoring architecture of the power grid monitoring and management system in an exemplary embodiment according to the present invention. For example, input data is provided by Control Areas to NERC over a secure connection using NERCnet **211** during data acquisition and validation **210**. The data may have been sent, for example, by one or more (up to all) of **123** Control Areas. The received data is archived (i.e., collected and concentrated) in one or more NERC database servers **216**. The data may also be processed using ACE and/or AIE applications. Output results go, for example, via XML, and SOAP technologies to a browser base clients.

The archived data may also be provided to NERC applications and web server **218**. The NERC applications and web server communicate with an early notification e-mail server **222** and/or Reliability Authorities web browser **220** over the Internet. For example, The NERC applications and web server may broadcast ACE-AIE key data to the Reliability Authorities every 60 seconds. The early notification e-mail server **222** may be used to notify abnormal events via e-mail **212**. The monitoring and tracking by 22 Reliability Authorities may include graphic and geographic displays using the performance monitoring technology platform of the power grid monitoring and management system of the present invention.

FIG. **16** is a screen shot **220** that illustrates a multiple view architecture of a display of the power grid monitoring and management system in an exemplary embodiment according to the present invention. The screen shot includes a real-time monitoring panel **222** used for graphical monitoring, a tracking panel **224** used for displaying tracking information, and a forecast panel **226** used for displaying prediction. The screen shot **220** also includes a text data/horizontal scroll panel **228** for viewing/scrolling text data.

In an exemplary embodiment according to the present invention, the CMS of the power grid monitoring and management system provides to Security Coordinators the tools to monitor each Control Area (CA) within their area of responsibility. Using the CMS, each Control Area will be reporting their ACE and AIE. For example, each of the Control Areas may report in one-minute intervals its ACE, frequency and AIE data through the NERCnet to the NERC Web Server. This data may be matched to the ACE/Frequency validation Matrix, the ACE-CMS database and presented back to each Security Coordinator utilizing the CMS. The compliance monitoring (reliability compliance) may also include CPS monitoring and inadvertent monitoring.

Therefore, the Security Coordinator will have the ability to view the CA performance using the graphic geographic visualization for Interconnections, Reliability Regions, Reliability Authority, Control Area and RTOs. Within these graphic displays the local hourly ACE may be presented in 2D and/or 3D. The power grid monitoring and management system also allows the user to display the ACE over different periods of time. These periods of time may range from the last scan to a thirty day history. The selection of all the Control Areas to an individual Control Area may be available to the user. In the described exemplary embodiment, there are three basic views for use in viewing these areas. An interactive replay of historical data may also be available. The replay element may, for example, allow for 24 hour, 48 hour, 7 day and 30-day replays.

The exemplary CMS presents the user with several different graphics. The Cave diagram is one of those graphic that is used as a tool to represent frequency/ACE, frequency/CPS**1** and Epsilon**1**/calendar. The CPS**1** pertains to a limit, which is a constant derived from a targeted frequency bound reviewed and set as necessary by the NERC Performance Subcommittee. Over a year, the average of the clock-minute averages of a Control Area's ACE divided by -10β (β is control area frequency bias) times the corresponding clock-minute averages of interconnection's frequency error must be less than this limit to comply with CPS**1**. To comply with CPS**2**, the average ACE for each of the six tem-minute periods during the hour (i.e., for the ten-minute periods ending at 10, 20, 30, 40, 50 and 60 minutes past the hour) must be within specific limits, referred to as L_{10}. An Epsilon (ϵ) is a constant derived from the targeted frequency found. It is the targeted root mean square (RMS) of one-minute average frequency error from a schedule based on frequency performance over a given year.

The Cave diagram **230** in FIG. **17** represents a Frequency/ACE diagram. Time is displayed on the horizontal axis. The upper graph vertical axis **232** displays the ACE. The lower graph vertical axis **234** displays the frequency. These two elements are used to develop the Cave graph. This type of graph is used as a tool for the review of current data as well as historical data in an exemplary embodiment according to the present invention.

The ACE function allows the user to view data for Epsilon**1**, ACE, and CPS**1**. Hence, the user is allowed to view the global, local or tracking data depending on what the user requires can disseminated the data further. The global function may be used to look at one or more of the Epsilon, the local ACE and tracking CPS**1**.

Referring back to FIG. **11**, the CMS receives data from the Control Areas (Data Collection **162**) and compares this received data to the submitted compliance data from each

Control Area (Standards & Algorithms **166**). The results of these comparisons are then displayed graphically (Visualization **164**) on a geographical map (Geography **168**). The five tiers of display start with the ISO RTO, Control Areas Reliability Authority, Reliability Regions and Interconnections.

FIG. **18** is a screen shot **240** of a default display for a Reliability Authority in an exemplary embodiment according to the present invention. The boundary tabs that appear at the top left side of screen represent the reliability organizations entry points. The five boundary tabs that are used for the CMS in the described exemplary embodiment are as follows: 1) Interconnections; 2) Reliability/Regions; 3) Reliability Authority (default); 4) Control Area; and 5) ISO RTO.

The Interconnection Map is divided into the four (4) NERC Interconnections, West, East, Quebec and Texas. The Reliability Region tab allows the user to view the map in a Region format. The Reliability Authority tab allows the user to view the **20** Reliability Authority areas of responsibility. Further, the Control Areas tab will give the user a map of all the NERC Control Areas. In addition, the ISO RTO map displays the thirteen (13) RTOs. In each of these maps, the Interconnections and/or other areas that do not submit data to the CMS are shown in black. In FIG. **18**, for example, Texas is shown in black as it is not currently submitting data to the CMS.

In each of the five boundaries, the current ACE and ACE/L_{10} data is displayed. The corresponding data is presented in a dynamic window **244** that appears at the bottom center of each map. As shown in FIG. **18**, the dynamic window has four tabs: 1) Overview; 2) Worst/Best CA's; 3) Reliability Authority Data, which changes to the boundary selected); and 4) Control Area (inner circle).

In the power grid monitoring and management system of the described exemplary embodiment, a 3D map may also be displayed. In addition, the network lines may be generated on the map. Further, the user may also be able to view global Epsilon for the Interconnections. Epsilon is a function of frequency. It is a constant derived yearly from the targeted Interconnection frequency deviations found from the prior year. This constant is used to compare the last hour frequency performance against this constant, and used to assist the Regional Authority on knowing how the Interconnection control has performed. For example, when the constant and measured value equal a number between 0-8 the map may be colored in blue ("good") for that Interconnection. Should the comparison of the Epsilon be greater than 8, but less than 10 then that Interconnection may appear as green ("satisfactory") on the Interconnection map. Similarly, the Interconnection may appear yellow ("warning") between Epsilon of 10-11 and red ("violation") for Epsilon greater than 11.

The Epsilon for the selected one or more Interconnections for the past 24 hours may be viewed, for example. FIG. **19** is a screen shot **250** of an Interconnect-Epsilon map in a three-panel display in an exemplary embodiment according to the present invention. It can be seen in a first panel **251** that the United States is divided into four Interconnections: 1) Western (W) **252**; 2) Eastern (E) **253**; 3) ERCOT (T or Texas) **254**; and 4) Quebec (Q) **255**.

The user may select one or more Interconnections for view. In the screen shot **250**, the "Daily Interconnection Map—Last 24 Hours Epsilon" **251** occupies the first panel. The "Daily Image Panel" **256** is in the upper right hand corner, and the "Daily Plot Panel" **258** is located in the lower right hand corner of the display. To have any one of the panels viewed as a full screen for better viewing, the desired panel may be right clicked to bring up a pop-up menu. By selecting "Maximize", the Panel may be shown as a full screen. The power grid monitoring and management system also allows for replaying using a replay function, for example. The replay may be up to 24 hours or more, for example. The replay speed may also be controlled to be slower and/or faster.

FIG. **20** is a screen shot **260** of a local view for a Control Area map in an exemplary embodiment according to the present invention. The graphic in the view of FIG. **20** shows the ACE and ACE/L_{10}. The Control Areas' ACE and/or ACE/L_{10} may be color coded so that as the Control Area's "ACE" changes the colors may be represented for the Control Area. For example, the ACE of −200 to −100 may be represented by red, −100 to 0 by yellow, 0 to 100 by green and 100 to 2000 by blue.

Also for the local view, a three-panel display may be displayed for a specific Control Area. The adjacent Control Areas may be defined as two Control Areas that are interconnected: 1) directly to each other; or 2) via a multi-party agreement (e.g., ISO and Power Pool agreements) or transmission tariff. Selecting Adjacent **0** may show only the Control Area, Adjacent **1** may show adjacent Control Areas, and Adjacent **2** may go out to the second level out away from the selected Control Areas. Selecting All may select all Control Areas. An actual interchange is a metered interchange over a specific interconnection between two physically adjacent Control Areas. An inadvertent interchange is a difference between the Control Area's net actual interchange and a net scheduled interchange.

For example, FIG. **21** is a screen shot **270** of a current Control Area map for a selected Control Area **272** in an exemplary embodiment according to the present invention. The selected Control Area **272** is shown in yellow on the ACE map. The upper right hand corner shows a last hour ACE **274**. This display is broken into 10-minute increments. A Cave graph **276** displays frequency and ACE for the last hour. The last hour ACE and the hourly Cave may also be displayed separately in the full screen. Similar to the global view, the local view ACE may be replayed for last 24 hours or more, during which the replay speed may be adjusted to become faster and/or slower.

FIG. **22** is screen shot **280** of a CPS map in an exemplary embodiment according to the present invention. The CPS map in the described exemplary embodiment is the same for each of the five boundary tabs. The CPS map may be color coded to visually give the user, for example, a view of the number of items in the ten (10) minute window of CPS**1** that the ACE did not cross zero for the last hour when compared to the Control Area's stated CPS**1**. For example, blue may represent 0 to −100%, green may represent 0 to 100%, yellow may represent 100% to 200%, and red may represent 200% to 1,000%.

By selecting the Control Area, and selecting a daily or monthly view, a three-panel view may be obtained for the Control Area and/or adjacent areas. For example, FIG. **23** is a screen shot **290** of a three-panel view in an exemplary embodiment according to the present invention. This particular map, for example, was generated using Adjacent **1** feature. From this screen, a replay of last 24 hours or more may be obtained. Further, the replay speed may also be controlled to be faster and/or slower.

FIG. **24** is a screen shot **300** of a data collection tool in an exemplary embodiment according to the present invention. The data collection tool may allow the user to view/extract raw data from the NERC database. This tool may be used to view the data that has been collected for the user to analyze.

Using the collected data, one or more charts may be generated as shown on a screen shot **310** of FIG. **25**, for example.

FIG. **26** illustrates utilization of NERC ACE-frequency monitoring **315** in an exemplary embodiment according to the present invention. The power grid monitoring and management system receives an early abnormal notification **320**. Then a root cause assessment **322** is performed for Regions and Control Areas with ten (10) worst ACEs, for example. Of these Regions and Control Areas, the root cause is pinpointed (**324**). Further, the Interconnection Control Areas Frequency-ACE and Root Cause Control Area ACE-Frequency are analyzed (**326**, **328**).

FIG. **27** illustrates a screen shot **330** of a supplier-Control Area performance for AGC and frequency response application in an exemplary embodiment according to the present invention. For example, as can be seen in a first panel **332**, real-time monitoring can be performed by zones, resource types and/or by owner. Actions/results may be viewed through horizontal scrolling and/or tabular display **338**. Further, a simulation or replay may also be performed/displayed. In the other panels **334** and **336** of the three-panel display, a historical performance tracking and delta forecast for the next six (6) ten minute periods, respectively, are also displayed.

FIG. **28** illustrates a market monitoring system **340** in the power grid monitoring and management system in an exemplary embodiment according to the present invention. In the market monitoring system **340**, a market monitoring center **342** (in the power grid monitoring and management system) receives systems conditions **344** such as market power, price spikes, demand forecast error, safe regulation bands and/or new control metrics. Also, the market monitoring center **342** receives market metrics such as blue alert, green alert, yellow alert and/or red alert. Then the market monitoring center performs actions **347** such as market performance metrics notification, remedial actions (e.g., re-dispatch), emergency actions and/or suspend rules. Further, the power grid management system monitors system conditions, track market metrics, assess predictive risk management, and the like (**348**).

FIG. **29** illustrates a screen shot **350** of a market monitoring application (of the power grid monitoring and management system) in an exemplary embodiment according to the present invention. For example, the system monitors (**352**) prices/spikes, imbalance energy, market power indices, and/or demand forecast error. Further, the system is used to take corrective actions (**354**) such as re-dispatch, price caps, suspend market rules and/or automatic mitigation. In two other panels of the three panel view of FIG. **29**, the system also tracks (**356**) historical performance by generator, control area, market and/or supplier, and/or the like, and bid sensitivities (**358**) for generator, portfolio and/or Control Area.

The power grid monitoring and management system in an exemplary embodiment according to the present invention performs Security Center monitoring. The Security Center operational hierarchy may include one or more of: 1) Security Monitoring Center using current and future synchronized data; 2) NERC **22** Reliability Coordinators; 3) RTOs/ISOs, Control Areas; 4) transmission only providers; 5) generation suppliers; and 6) load serving entry.

FIG. **30** illustrates a Security Center monitoring system (of the power monitoring and management system) in an exemplary embodiment according to the present invention. A Security Center **362** receives composite security indices **364**, which include synchronized data network, supply adequacy metric, voltage/VAR adequacy, congestion management and/or market dysfunction. The Security Center also receives security alerts **366**, which include red, orange, yellow, green and/or blue alerts. The Security Center **362** in coordination with a Security Coordinator **367** tracks composite security indices **368**, monitors composite security metrics **372**, assesses predictive risk management **374**, and coordinates with Reliability Coordinators level **370**. FIG. **31** illustrates a screen shot **380** of a real-time security monitoring application (of the power grid monitoring and management system) in an exemplary embodiment according to the present invention. The system performs a real-time monitoring of composite security indices (**382**), and also tracks the composite security indices (**388**). In addition, the system coordinates with NERC Reliability Coordinators. Further, the system also provides actions, phone numbers and e-mails to facilitate the coordination (**386**).

FIG. **32** is a block diagram of a NERC reliability functional model **390** in an exemplary embodiment according to the present invention. The power grid monitoring and management system in exemplary embodiments according to the present invention facilitates the integration process, focusing first on the applications required by the stakeholders within a dotted line **392**. Functions within the dotted line include reliability coordination **393** and compliance enforcement **394**, balance authority service acquisition **395**, load servicing entities procurement **396** and the actual usage of the services by the transmission operators **397**.

In an exemplary embodiment according to the present invention, the power grid monitoring and management system is adapted for the monitoring, tracking and short term prediction of CAISO CA and suppliers response to AGC, FRR, and ancillary services (A.S.) regulation performance/requirements. In the described exemplary embodiment, the power grid monitoring and management system will track and predict both the Control Area's and the supplier's performance for the above three services (AGC, FRR and A.S.). The power grid monitoring and management system, for example, may be used by the real-time operators, the operating engineering staff and/or management.

The real-time operators may obtain one or more of the following benefits through the present invention: 1) enhanced ability to monitor and track the CAISO Control Area and Suppliers response to AGC, including the ability to segregate into areas, (e.g., Northern and Southern California) and suppliers; 2) identify Control Area and supplier's actions, their performance and near real time predictions to frequency response; 3) identify and provide information for possible required changes in next hour's scheduled A.S. for Regulation; 4) identify and provide information for possible required changes in next day's scheduled A.S. for Regulation; and 5) one general overview display that show all three functions. More detailed displays may be available for each area.

The operating engineers may reap one or more of the following benefits from the power grid monitoring and management system of the present invention: 1) provides them with unit specific performance information; and 2) provides them with information that allows them to work with plant owners to improve their response to AGC, FRR and A.S. Regulation. Further, the power grid monitoring and management system of the present invention may provide to the management near real-time operational information that allows them to evaluate the effectiveness of market rules and tariffs.

The power grid monitoring and management system may also provide reliability services to the relationships between

operational reliability objectives, services required for reliable operations and the roles and responsibilities for the control and operation authorities. For example, the reliability services may be provided to transmission reliability, supply resources and demand balance, and A.S. markets.

Returning now to FIG. **6**, the top half of FIG. **6** shows the architectural overview of the application of the power grid monitoring and management system for monitoring real-time control performance at the reliability coordinator level. The applications have been designed, deployed and tested for the NERC Reliability Coordinators. The bottom half of FIG. **6** shows the overview for the Control Area level. The power grid monitoring and management system integrates response to AGC, FRR and A.S. to effectively visualize how the CAISO Control Area and Suppliers are performing for each of the three areas.

A System operator normally has an available range of AGC control, both up and down, displayed on some type of general overview. These values, in today's systems, are normally mapped into these overviews as provided by successful bidders of Regulation A.S. This AGC range & ability governs many decisions made on real time (i.e., magnitude of Control Area Interchange ability, coverage of manually directing on-line generators for various reasons, etc.). In one exemplary embodiment, the AGC module of the power grid monitoring and management system qualifies the accuracy and performance of that AGC range as it happens and records it. For example, the AGC module may display and track how much a generator on AGC control is signaled to move in MW and presents various displays/documentation on how well (or not) that requirement is/was being met.

The user may have the ability to see generator response to AGC in real-time. Aside from over-all aggregate views, the user can display (select or "turn on") a segregation of generators into zones (e.g., Northern California and Southern California) and suppliers, which could aid real-time decisions. As an example, monitoring could show all generators in the north meeting 100% response requirements and only 70% in the south, dictating possible manual intervention for an upcoming large ramp that might leave undesired loadings on constrained paths (e.g., Path **15**). Aside from regional segregation ability, the power grid monitoring and management system can also separate displays into types of generators (i.e., 150 Mw, 750 MW, Hydro, etc.).

The displays for tracking may show the response performance of suppliers to AGC for the previous hour, day and week. By utilizing historical response data, the application may predict the response performance of each supplier to AGC for the next 10, 20, 40 and 60 minutes.

In Summary, the AGC module may achieve/produce one or more of the following: 1) a visual representation of the real-time performance of each generator on AGC; 2) various options of displaying aggregate and detailed information on AGC units; 3) provisions for alarm points when established parameters are met; 4) selectable Time Period Displays and Printouts, (Previous Hour, Day, Week) of a generator's performance. They can be used for monetary penalties in billing and for various analysis efforts; and 5) can be used for near real time prediction. (10, 20, 40 and 60 minutes). The system overview visualizations to show the above functionalities will be discussed later.

In an exemplary embodiment according to the present invention, the power grid monitoring and management system provides control area and suppliers response performance monitoring, tracking and prediction to FRR. Historically, having NERC Standards in place has provided adequate assurance that the Control Areas and interconnected generators within each Interconnection, as well as load shedding, were able to effectively respond to contingencies and adequately arrest frequency excursions, thereby meeting design expectations. Within the WECC (i.e., Western Interconnection), the normal and expected change in system frequency for the loss of 1,000 MW of generation has been a 0.1 Hz decay. In recent years, however, it is not unusual to experience a 0.1 Hz decay in system frequency with only a 300 or 400 MW loss of generation. So FRR Monitoring, Performance Tracking and Prediction implementation at CAISO is desirable.

The following example illustrates a frequency decay by 0.2 Hz for a loss of about MW. It appears, for whatever reasons, that the overall frequency response of the interconnected system has changed significantly, in a negative way. The exemplary embodiment implements new standards, specifically addressing the issue of frequency response, and establishing the necessary monitoring and tracking system (s) to evaluate the performance of the frequency responsive resources and the Control Area.

A Control Area's frequency response performance is the result of how good or bad all the Frequency Response resources connected to the transmission system respond and perform. This application will monitor, track, and project Frequency Response Reserves performance in the CAISO Control Area.

Major functions of the FRR module may include one or more of:

1) Performance—monitor the performance of the CAISO's Control Area response to frequency excursions, calculate the MW/0.175 Hz deviation and determine if the Control Area is in compliance with the proposed NERC/WECC FRR standards. In addition, the application may monitor the actual performance of each of the frequency responsive resources that are expected to support the Control Area response to frequency excursions and calculate their contribution per MW/0.175 Hz deviation. This module will provide the answer to the question, "Which resources are contributing to the Control Area's overall compliance with the Frequency Response Reserves (FRR) standards?";

2) Tracking—time tagging and archiving of actual data associated with monitoring performance and MW/0.175 HZ deviation performance of the Control Area to frequency excursions, as well as the performance of the individual frequency responsive resources. Data may be stored in a time series database and used to present the pattern and behavior of specific resources. Historical data may also be used to feed the prediction module. It can also be an ingredient of any required disturbance control standard (DCS refers to the standard which requires the ACE to return either to zero or to its pre-disturbance level within 15 minutes following the start of the disturbance, which is a) any perturbation to the electric system, or b) an unexpected change in ACE that is caused by the sudden loss of generation or interruption of load.);

3) Probabilistic prediction—provide the CAISO staff with a prediction of the expected performance of the frequency response resources to the next frequency excursion. A more accurate forecast of the upcoming performance in meeting the FRR standards may allow the CAISO to maintain and improve system reliability and market efficiencies. If the prediction module of the application determines that the anticipated resource configuration is inadequate in meeting the FRR requirement, it can produce a suggested alternative or additional resource requirements; and

4) Visual Analysis—the power grid monitoring and management system visual analysis layer may facilitate the

interpretation of the results from each of the major functions. Taking advantage of the visualization technology available in the power grid management system, it may present past, current and near term future information to the CAISO staff on tabular, graphical and/or geographical displays. The application may provide the ability to segregate suppliers into zones, such as Northern & Southern California, and also of the various "types" of generators.

Load shedding on non-critical loads is another FRR resource that the system operator may have to adjust frequency. For this reason, the performance of load shedding (measured as MW/0.175 Hz) as a frequency control resource may also be determined, tracked and predicted.

The suppliers response performance to AGC previously explained, displayed and recorded what each and all Control Area regulating generators were signaled to move and how they performed, relative to that signal. This application may track and record the delta or difference between what the supplier bid in regulation service for the Hour Ahead Market and its actual response.

Ancillary Service of regulation is normally prescheduled for the hour ahead (and day ahead) via the marketplace. A successful supplier of regulation will normally have an up and down magnitude, although one direction only can occur. In conjunction with that MW range, a ramping (rate of change) magnitude is also provided by the supplier, normally in percentage or MW/minute.

The displays for monitoring of this application will show and record how well a generator is providing regulation, follows control signals sent by CAISO's Energy Management System Computer and will compare it to the parameters (ramp rate) provided by the supplier (Bid, Contract or Plant Information) in the Hour Ahead or Day Ahead Market.

The displays for tracking will show the supplier's historical response performance to the hourly ancillary services market for the last day and week. This information could be shared with the suppliers that provide this service, to improve quality, or even be made inclusive of the payment structure when stipulated non-performance occurs.

The displays for prediction will show the suppliers predictive response performance to hourly ancillary services one, two, three and/or four hours ahead. For example, suppose next hour's Regulation range is displaying a 500 MW upward quantity, with a 25 MW/Min aggregate ramp rate, provided by the marketplace. Utilizing historical performance data, this application will note what sources are providing this regulation range and "quantify" it for the System operator. It could, for example, note that only x-amount is available over a designated time period or that only 15 MW/Min rate of change is achievable. If that reality is unacceptable, the system operator may have the option of utilizing other hourly or 10 minute sources to mitigate adverse balancing and reliability effects. This will apply to either increasing or decreasing load requirements.

A System operator will often have a need to appraise what resources have been planned for some near short term future hours. This can be the result of unplanned outages of generators, internal transmission lines, interconnection transmission lines and other events. This application gives a little longer look than the Hour Ahead program in respect to Ancillary Services Regulation.

Similar to the Hour Ahead function, the monitoring associated with this module is focused on those regulation ancillary services that were attained from the Day Ahead Market only and will display relative comparisons of actual performance vs. market bids in these regulation services.

Historical performance data for the past day and week will be available in the displays of this module. This data could be used in conjunction with the Hour Ahead Performance by comparing records for various validations or determinations between the two markets. They can also be shared with the suppliers for improved quality of service or included in the payment structure for performance penalties. The power grid management system may also allow the user, using historical performance data, to predict the performance of the day ahead committed resources of ancillary services for regulation by choosing the display option of Day Ahead Market.

Based on NERC current reliability guides, drafts standards for NERC and WECC Frequency Response Reserves (FRR) and input from the CAISO's system operators and management, the key functional capabilities for the power grid monitoring and management system for CAISO may include one or more of: 1) performance monitoring of CAISO's CA and suppliers to AGC; 2) performance monitoring of CAISO's CA and suppliers to FRR; and 3) performance monitoring for CAISO's CA and suppliers to Hourly and Day-Ahead Ancillary Service Regulation.

The Control Area's frequency response performance is the result of how good or bad all the frequency responsive resources connected to its transmission system perform. The challenge for the Control Area is how to determine the actual performance of each resource vs. expectations.

Although this application has the ability and will evaluate the Control Area performance to determine compliance with the FRR Standards, the primary focus of the application is to monitor and track the actual performance of the individual frequency responsive resources connected to the grid. As stated above, it is the performance of each and every resource connected to the CAISO's grid that will determine the Control Area's overall frequency regulation performance.

The purpose of the proposed application is to provide sufficient and meaningful information for the CAISO management and staff to: 1) maintain system reliability and ensure compliance with NERC and WECC reliability standards, by monitoring in real time the response performance of CAISO's CA and suppliers to the AGC, FRR and A.S.; and 2) improve the efficiency of the A.S. market. The Table 1 below, for example, shows functionalities in an exemplary embodiment according to the present application.

TABLE 1

Overview of Functionalities

	Service		
Function	CA&Suppliers Response to AGC	CA&Suppliers Response to FRR	CA&Suppliers Response to A.S.
Monitoring	Scheduled vs actual response in last one-minute interval Performance Indices	Expected vs actual response in last frequency excursion Performance Index	Last Bid vs actual response Performance Index
Tracking	Previous hour, day and week scheduled vs actual response	History of Deviations (MW/0.175 Hz) performance to	Last day supplier response to A.S. markets Last week

TABLE 1-continued

Overview of Functionalities

Function	Service: CA&Suppliers Response to AGC	CA&Suppliers Response to FRR	CA&Suppliers Response to A.S.
	Historical Performance Index	frequency excursions of CA and suppliers Historical Performance Index	supplier response to A.S. markets Historical Performance Index
Predictions and Probability bands	10 Minutes Ahead 20 Minutes Ahead 40 Minutes Ahead 1 hour ahead Probability bands Bad data identification and replacement	Next frequency excursion, twenty and sixty seconds response Probability bands Bad data identification and replacement	1, 2, 3 and 4 hours ahead for hour market Day ahead market Probability bands Bad data identification and replacement

It should be noted that the tracking function may serve as a simulation tool.

In monitoring the response performance to AGC of CAISO CA and suppliers, the system operator may first look at the display of the one-minute supplier control error for each resource. A pie graph may be presented for each resource that is being monitored. Part of the pie indicates the expected response, other part the actual response and the last part the difference between the actual and the expected response. The pie will be color coded to indicate the performance of the generator response for the last one-minute period. The cylinder height, also color-coded, represents the performance index. The performance indices are defined herein later on.

For the tracking of the response performance to AGC of CAISO CA and suppliers, the system operator has a chart available with the historical values for the period that he/she specifies. The response prediction may also be offered to the System operator, for the next 10, 20, 40 and/or 60 minutes.

The system operator may then use these three pieces of information to decide how much to rely on each resource for AGC. For example, suppose actual part of the pie is red and the cylinder height is red. This means that the supplier is performing poorly recently. Analysis of the historical performance (tracking function) provides additional information to decide how reliable the supplier is. If the historical performance is poor, the forecast will also be poor. The System operator will integrate all this information to decide on a course of action for the resource under consideration.

Similar functionality will be offered for monitoring, tracking and predicting the response performance of CAISO CA and suppliers to FRR. Instead of one-minute values as in the resource response to AGC, however, the resource response to the historical average to frequency excursions may be displayed. Each supplier may be represented by two color-coded pies and a cylinder. The pie indicates the generator FRR actual response to the last frequency excursion and its expected response. The height of the cylinder may, for example, represent the performance index of the generator.

The functionality offered for monitoring, tracking and predicting the response performance to A.S. markets (hourly and daily) may, once again, be similar to the one of the previous two applications. Each supplier is represented by two color-coded pies and a cylinder. The pie represents the most recent response for the day ahead and hour ahead bids and the bids made by the suppliers in the A.S. markets. The cylinder height represents, as before, the performance index.

FIG. **33** illustrates a geographic-graphic visualization overview **440** of a control area and suppliers performance monitoring and prediction platform for AGC, FRR and regulation A.S. in an exemplary embodiment according to the present invention. As shown in FIG. **33**, the CAISO System operator will have available displays to monitor for the current time, last 24-hours and last X-minutes (default 10-minutes) both their CA and the individual suppliers response performance, forecast and tracking performance of CAISO AGC, Frequency Response Reserves (FRR), and hourly and daily Regulation Ancillary Services markets. In addition, besides having CA and suppliers performances for each service, CAISO System operators will also have available an integrated window that will show continuously the CA and suppliers performance for all four services simultaneously, and replay capability for displays on either of the panels from the 3-panel displays.

This application of the power grid management system allows the CAISO System operators and management to identify via 3-panel displays the CA and suppliers performance for each service on geographical displays for current time, the last ten minutes on co-plot displays, and for the past 24-hours on image-displays and user selected suppliers predictive performance. The bottom of the 3-panel displays will be user selectable, to switch from tabular text window correlated with the data in the 3 panels, to optionally show to System operators in a continuous horizontally scrollable window, the performance indices for AGC, FRR and regulation ancillary services. The indices will replay continuously for a selectable period of time that will include the prediction period.

FIG. **34** is a screen shot **450** of a panel view for control area and suppliers performance for, AGC, FRR and A.S. in an exemplary embodiment according to the present invention. Its can be seen in FIG. **34** that there are five tabs at the top-left corner. Each of them presents a 3-panel display with the main panel, showing in a 3D map, the selected suppliers performance for the service selected and the other two panels showing the selected suppliers performance for the other two services. The three tabs at the top-right present the window for username/password, interface for user enterable parameters, and the help displays. The help displays, for example, may be based on Microsoft® PowerPoint® presentations.

The map and the cylinder pie-charts in the main panel display from the 3-panel display in FIG. **34** shows the current response of each supplier, selected from categorical options from a RMB menu, to the service selected from the tab. The other two panels also show the performance of the selected generators for the other two services.

The center-bottom of the 3-panel displays is user selectable to switch from tabular text window correlated with the data in the 3 panels, to optionally show to System operators continuously in a horizontally scrollable window the performance indices for AGC, FRR and regulation ancillary services. The indices will replay continuously for a selectable period of time that includes the prediction period. The three windows at the left-bottom of the screen contain the date/time for the data being displayed, an option to hold the

automatic data refresh, and a yellow window to indicate the current action taken by the user

FIG. **35** is a screen shot **460** of a panel view for control area and generator response to AGC in an exemplary embodiment according to the present invention. FIG. **35** shows the 3D map and cylindrical pie-charts in the main panel display from the 3-panel display representing the current response of each generator, selected from categorical options from an RMB menu, to AGC, with the cylinder-height representing each generator performance index. The color of the CAISO control area may represent the response to AGC of all the suppliers providing the control area, represented by the performance indices previously discussed herein.

The image on the top-right panel shows the performance tracking of each of the suppliers online, selected from the RMB option, and may be color coded for the last 24-hours. The plot on the bottom-right panel shows the predictive plot. This plot includes a multi-series, time-based, linear chart. One series represents the recorded values of a variable over time and the second represents the predicted value for the same variable over the time period and for X additional predicted values. The plot also includes a vertical reference-line indicating the current time, relative to the time period being displayed. Multiple instances of this plot are used in the display, as illustrated, and the user selects the values for display via an options dialog.

The center-bottom of the 3-panel displays will be user selectable to switch from tabular text window correlated with the data in the 3 panels, to optionally show to system operators continuously in a horizontally scrollable window the performance indices for AGC, FRR and regulation ancillary services. The indices will replay continuously for a selectable period of time and will include the prediction period.

The three windows at the left-bottom of the screen contain the date/time for the data being displayed, an option to hold the automatic data refresh, and a yellow-window to indicate the current action taken by the user.

The two main windows at the right-bottom of the screen contain the navigation buttons that must be implemented as shown, and the replay bottoms that also must be implemented as shown.

The three tabs at the top-right present the window for username/password, windows for user enterable parameters, and the help displays based on Microsoft® PowerPoint® presentations.

FIG. **36** is a screen shot **470** for a panel view for control area and generators response to frequency response in an exemplary embodiment according to the present invention. FIG. **39** above shows the CAISO geographic map and color coded cylindrical pies placed at the geographic location of each selected generator, with part of the pie representing the generator latest FRR response, the other part its expected FRR value and the last part the difference between actual and expected response. The height of the cylinder represents the FRR performance index for each selected generator.

The plot on the top-right panel shows the FRR performance tracking of each of the generators online, selected from the RMB option during the most recent frequency disturbances. The plot on the bottom-right shows the current selected generators FRR performance together with its performance variance for the hour, and the value predicted for the next excursion.

FIG. **37** is a screen shot **480** for a panel view for control area and generators response to regulation A.S. in an exemplary embodiment according to the present invention. FIG. **40** shows the CAISO geographic map and two concentric circles located at the geographic location of each selected generator, with the inner most circle representing the generator actual response for both the day-ahead and hour-ahead bids, and the outer most circle representing its Ancillary Service (both day-ahead and hourly-ahead) scheduled values. The height of the cylinder represents the Ancillary Services (day-ahead and hour ahead) performance indices for each selected generator.

The image on the top-right panel shows the Supplier Control Performance System (SCPS) for each of the generators selected, color-coded for the last X-Minutes (default 10-minutes). The plot on the bottom-right panel shows the predictive plot. This plot consists of a multi-series, time-based, linear chart. One series represents the recorded values of a variable over time and the second represents the predicted value for the same variable over the time period and for X additional predicted values. The plot also includes a vertical reference-line indicating the current time, relative to the time period being displayed. Multiple instances of this plot are used in the display, as illustrated, and the user selects the values for display via an options dialog.

FIG. **38** is a screen shot **490** of a common view for performance of AGC, FRR and X-Minutes Ancillary Services Regulation (Default 10-Minutes) in an exemplary embodiment according to the present invention. The format of FIG. **38** is equivalent for all three services using the corresponding performance data and indices. The main-panel shows the condition plot. It is similar to a scatter plot, created using the variables of one of the three services, the parameters of one of the three services and the names of the selected generators for a configurable, 10 minute time period (at 1 minute sampling frequency).

The following describes how the chart should be created as shown in FIG. **38** in an exemplary embodiment according to the present invention.

1) Run the appropriate database stored procedure.

2) Determine from the user interface the value to perform grouping, by performance, parameter or time.

3) Determine the unique grouping values.

4) Determine the median parameter value for each generator (using the whole dataset) and order the generator list by that value.

5) Create a scatter plot for each unique grouping value, with the data value plotted on the X-axis. Each scatter point is colored according to a color map defined in a configuration file (Red/Yellow/Green).

6) The scatter plots will be arranged on a grid by increasing value, left to right, top to bottom.

The image on the top-right panel shows the performance index for each generator selected, color-coded for the last X-Minutes (default 10-minutes). The cave-plot at the bottom-right shows at the top the response MW of any generator selected from the image-plot, and at the bottom the scheduled MW for the selected generator.

It will be appreciated by those of ordinary skill in the art that the invention can be embodied in other specific forms without departing from the spirit or essential character thereof. The present invention is therefore considered in all respects to be illustrative and not restrictive. The scope of the present invention is indicated by the appended claims, and all changes that come within the meaning and range of equivalents thereof are intended to be embraced therein.

What is claimed is:

1. A real-time performance monitoring system for monitoring an electric power grid, comprising:

a monitor computer for monitoring at least one of reliability metrics, power grid operations metrics, generation metrics, transmission metrics, suppliers metrics, grid infrastructure security metrics or markets metrics over a plurality of control areas of the electric power grid operated on a plurality of different platforms by a plurality of different business systems or companies;

a database for storing the metrics being monitored by the monitor computer; and

at least one display computer in at least one of said plurality of control areas of the electric power grid, the at least one display computer having a monitor for displaying a visualization of the metrics being monitored by the monitor computer,

said at least one display computer in one of said plurality of control areas being adapted to enable an operator located in and responsible for monitoring the one of said plurality of control areas to monitor one or more of said plurality of control areas that are different from the control area in which the operator is located.

2. The real-time performance monitoring system of claim **1**, wherein the monitor computer includes an application for monitoring the reliability metrics, and wherein said application performs real-time monitoring of at least one of voltage/VAR (volt-ampere reactive), ACE (area control error)-frequency, AIE (area interchange error) schedule or phasor measurements for the electric power grid or a portion thereof or for one or more of said plurality of control areas, wherein the electric power grid covers a wide area across one or more cities, counties, states or countries.

3. The real-time performance monitoring system of claim **1**, wherein the monitor computer includes an application for monitoring the generation metrics, and wherein said application performs real-time monitoring of at least one of suppliers and control area responses to at least one of AGC (automatic generation control), a frequency response, ancillary services or a ramping response.

4. The real-time performance monitoring system of claim **1**, wherein the monitor computer includes an application for monitoring the grid infrastructure security metrics, and wherein said application performs real-time monitoring of at least one of system vulnerability including phasor measurements and changes thereof or exposure in terms of at least one of population or cities.

5. The real-time performance monitoring system of claim **1**, wherein the monitor computer includes an application for monitoring the markets metrics, wherein said application performs real-time monitoring of at least one of generation market power or price spikes.

6. The real-time performance monitoring system of claim **1**, wherein at least one of the monitor computer or said at least one display computer performs at least one of historical tracking, prediction or actions related to the metrics being monitored, wherein the actions related to the metrics being monitored include actions related to one or more violations of one or more predefined thresholds, wherein the one or more violations are communicated in real time through alarms or other communication systems.

7. The real-time performance monitoring system of claim **6**, wherein the monitor displays a visualization of data representing said at least one of historical tracking, prediction or actions related to the metrics being monitored.

8. The real-time performance monitoring system of claim **6**, wherein the prediction includes at least one of a near real-time forecasting or a "what if" sensitivity analysis.

9. The real-time performance monitoring system of claim **1**, wherein the monitor concurrently displays at least one dynamic geographic display and a plurality of data or text panels for at least one of monitoring, tracking, prediction, actions or mitigations.

10. The real-time performance monitoring system of claim **1**, wherein the monitoring of the metrics can be performed real-time and/or near real-time.

11. The real-time performance monitoring system of claim **1**, wherein the monitoring system utilizes data from or is integrated with at least one of SCADA (Security Control and Data Acquisition), EMS (Energy Management System), PMUs-PDCs (phasor measurement units-phasor data concentrators) or another control power system.

12. The real-time performance monitoring system of claim **1**, wherein an operator of at least one of the monitor computer or said at least one display computer can define an application to monitor metrics, which are related to the electric power grid at the local level, control area level, or regional level covering a wide area, which the operator desires to monitor.

13. The real-time performance monitoring system of claim **1**, wherein a display format of the visualization on the monitor can be customized by the operator.

14. The real-time performance monitoring system of claim **1**, wherein the monitor computer is a server and said at least one display computer comprises a client in a server-client architecture.

15. The real-time performance monitoring system of claim **1**, wherein the monitor computer is a dedicated server.

16. The real-time performance monitoring system of claim **1**, wherein the monitor computer and said at least one display computer communicate with each other in a web environment or over a secure proprietary network.

17. The real-time performance monitoring system of claim **1**, wherein the operator of said at least one display computer can interactively collect historical data and view a visualization of the historical data in tabular, graphics or a customized format.

18. The real-time performance monitoring system of claim **1**, wherein the operator of said at least one display computer can interactively create data reports from the metrics stored in the database.

19. The real-time performance monitoring system of claim **1**, wherein the monitor computer monitors proximity to potential system faults, and said at least one display computer graphically represents the proximity to potential system faults on the monitor.

20. The real-time performance monitoring system of claim **1**, wherein the monitor computer tracks, identifies and saves data on abnormal operating patterns in the database, and the display computer displays a visualization of the abnormal operating patterns on the monitor.

21. The real-time performance monitoring system of claim **1**, wherein said at least one display computer enables the operator to define a display level to at least one of the electric power grid, one said control area or multiple said control areas.

22. The real-time performance monitoring system of claim **1**, wherein said at least one display computer in one of a plurality of control areas enables the operator in the one of said plurality of control areas to manage at least one grid portion corresponding to a different one of said plurality of control areas.

23. The real-time performance monitoring system of claim **1**, wherein the monitor computer performs wide area monitoring of the electric power grid using SCADA (Security Control and Data Acquisition) data and/or time synchronized data from phasors or other sources.

24. The real-time performance monitoring system of claim **1**:

wherein the reliability metrics, power grid operations metrics, generation metrics, transmission metrics, suppliers metrics, grid infrastructure security metrics or markets metrics for the electric power grid are monitored across a wide area covering multiple control areas and utilities;

wherein each of the plurality of grid portions includes a network of high voltage transmission lines and generators interconnected to the network that is spread out over the multiple control areas across the wide area;

wherein the plurality of grid portions are subject to power blackouts that spread or cascade over the wide area; and

wherein the operator is a reliability coordinator having responsibility to:

monitor the power grid metrics over the wide area for reliability management; and

prevent power blackouts that spread or cascade over the wide area.

* * * * *

CERTIFICATE OF FILING AND SERVICE

I hereby certify that on this 14th day of October, 2015, I caused this Brief of Appellant to be filed electronically with the Clerk of the Court using the CM/ECF System, which will send notice of such filing to the following registered CM/ECF users:

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Upon acceptance by the Clerk of the Court of the electronically filed document, the required number of copies of the Brief of Appellant will be hand filed at the Office of the Clerk, United States Court of Appeals for the Federal Circuit in accordance with the Federal Circuit Rules.

/s/ Art Hasan
Counsel for Plaintiff – Appellant

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Dated: October 14, 2015

/s/ Art Hasan
Counsel for Plaintiff – Appellant